PRACTICAL PHYSIOGRAPHY

FAIRBANKS

Frontispiece

FIG. 1.

Canyon of the Virgin River, southwestern Utah.

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PRACTICAL PHYSIOGRAPHY

BY

HAROLD WELLMAN FAIRBANKS, PH.D.

WITH NINE COLORED MAPS AND
THREE HUNDRED AND NINETY-FOUR ILLUSTRATIONS

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PREFACE.

The last few years have witnessed important changes in the text-books pertaining to Physical Geography. The study of the world as a fixed model has given place to the study of a world whose physical features are undergoing continual change. This change is in turn seen to affect the climate and the life conditions of plants and animals, and to have an important influence upon the activities of men.

The number of books treating the subject from this newer point of view has rapidly increased, and several of them are so excellent that there would appear to be scarcely room for another book covering the same ground in the same manner. It seems to the author, however, that the evolution of better methods of teaching Physical Geography is still going on. The student will never gain what he should from the study until the use of the text-book is supplemented, not by the indoor laboratory method, for that would take the life out of the subject, but by the study of nature itself in the great outdoor laboratory. It is not the amount of ground gone over; it is not what is memorized from a text-book; it is not watching experiments in the class room, which makes Physical Geography, or Physiography as we prefer to call it, of value in the high school. It is rather the gaining of an ability to understand the meaning of the phenomena of the land, the water, and the air, and the relation of all life to them. For this purpose nothing can take the place of excursions and the study of the real world.

The author has tried to work out in the present volume a practical concrete treatment of the subject along these lines. The book is intended as an aid to study, not as a compendium of information. Consequently a description of the world as a whole is omitted. Attention is devoted specifically to the region of the

United States, and the typical examples afforded by it are studied as representatives of world-wide processes.

The purely descriptive method has been discarded as far as practicable, the object being to lead the student to investigate and find out for himself. Instead of being told everything, he is led to use his observing and reasoning powers. It is not expected, however, that he will be able to answer all the questions without aid and direction from the teacher, and these should be given whenever necessary.

No separate chapters have been devoted to the relation between physical nature and life, but instead, this relation is brought out in its appropriate place in connection with each topic throughout the book. Such an arrangement, it is believed, will make the whole matter much more vital.

Another feature which the author trusts will meet with favor from the practical teacher is the distribution of the questions and exercises throughout each chapter in close connection with the descriptive portions to which they refer. The placing of questions and exercises by themselves at the close of each chapter puts a premium upon mere memorizing of the text and the omission of all practical work.

The field and laboratory exercises should be enlarged and adapted to the needs of the particular locality; for, unlike courses in Physics and Chemistry, which may be practically the same for all places, a course in Physiography should be emphasized along those lines which find their fullest development in the neighborhood of the school.

The illustrations are a marked feature of the book, and an understanding of them is as important as a knowledge of the text itself. Photographs have been used wherever possible, as they appeal with much more force to pupils of high school age than do diagrams or sketches. Most of the views are from the author's own negatives.

H. W. FAIRBANKS.

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PART I.

GENERAL PHYSIOGRAPHIC PROCESSES.

CHAPTER I.

THE EARTH.

The Earth's Surface. — The earth's surface is made up of land and water, and the whole is enclosed in an envelope of air. Multitudes of living things make their homes upon the land and in the water, while some spend a large part of their lives in the air.

The earth, in company with other planets, revolves around the sun, receiving from it light and heat. Without this life-giving influence the earth would be a dead ball of ice and rock.

The land surface is small in proportion to the water surface; and only a part of this land has a climate to which man is adapted, since many large areas are either too wet or too dry, too hot or too cold, for him to live in comfortably.

Illustrate the importance of light and heat for the growth of living things. Sketch roughly the outlines of those lands which would remain unsubmerged if there were a small increase in the amount of water, — enough, for example, to give an added depth of one thousand feet to the ocean.

The climate of a place is determined by many things, as you can easily learn from observation.

Give reasons for your conclusions as to whether, in the climate of your home, the most important factor is distance from the equator, elevation above the sea, direction of the wind, or position with reference to some large body of water.

Changes in Surface and Climate. — There are many reasons, the details of which you will learn later, for believing that the mountains, valleys, and coast lines have not always been where they are now. The character and position of these features have an important influence upon climate; and as they change, the climate also must change.

From what you know of the climate of highlands as compared with lowlands, what would be the effect of an uplift of two thousand feet upon the productions and industries of the country about your home?

As a region becomes warmer or colder, wetter or drier, during the slow changes of the surface which are everywhere going on, the plants and animals that inhabit it die unless they can adapt themselves to new conditions or move to another home.

Our world, then, is not like the globe in the schoolroom. That globe remains year after year in practically the same state in which it was left at the making; but the world, with all the living things upon it, is always changing. It is not the same this year as it was last, nor will it be the same next year as it is now.

Give some common examples of changes which you have observed in the surface of the earth caused by the action of water, ice, frost, wind, earthquakes, etc.

In order to understand how the world came to be as it is now, we must learn something about the materials of which it is made and of the forces which have been shaping its features through all its long history.

Let us suppose ourselves upon a high point, looking into a valley surrounded by mountains. The valley, the stream flowing through it, and the surrounding highlands, as well as the various species of plants and animals that inhabit them, have all had a history. If the mountains had never been formed, the climate and drainage would be different from what they are, plants and animals different from those now here would flourish, and quite possibly we should never have come to look upon the scene and to reason about it.

We cannot move from one place to another or engage in any particular kind of work without first taking account of the climate and of the forms of land and water. The study of these things is, then, very important, for it enables us to understand the meaning of the physical features and life about us, and the reasons for our being where we are.

Warfare of Forces. — The materials of the earth and the living things upon its surface are subject to the action of so many forces, that we can hardly say that anything is really lifeless and inert. Even the rocks, at first thought seemingly indestructible, decay just as truly as do animal bodies, although very much more slowly. Some of these forces act so slowly that one can discover no effect during one's lifetime; others, some of which you can undoubtedly mention, have destroyed thousands of people in a few moments. Man only, of all living things, is able, because of his superior intelligence, to reason about and take advantage of the forces of nature; making use of the favorable ones, and overcoming those that work for his destruction.

These forces with which we have to deal all our lives are of two opposite kinds which are at war with each other. One builds and the other destroys. The first, whose source is in the earth far beneath our feet, raises up the surface and makes it rugged and mountainous (Fig. 2). The second force is always busy destroying the work of the first. Unless the builder works faster than the destroyer, the latter will eventually wear away even the loftiest mountains and reduce them to the level of the sea (Fig. 3).

From your reading, describe some of the scenes characteristic of volcanic eruptions and of earthquakes. Mention all the possible agents by which the highlands might be worn down. Which one do you think is doing the most work?

A glass of discolored water taken from a stream during or after a rain will help make clear the work of destruction which the water is doing. Let the water stand until it becomes clear, and examine the muddy material in the bottom. What is the origin of this material?

Where did it come from and whither is the stream taking it? What effect must this process finally have upon the hills and mountains?

How different this muddy sediment of the river appears from the hard rocks forming the cliffs of the mountains and canyons. The river itself does not wear away much of this hard, solid rock, but there are other agents, such as moisture, carbonic acid, heat,

FIG. 2.

An extinct volcano. Mt. Shasta, California, seen from the north, across Shasta Valley.

and cold, which are slowly softening and crumbling the materials of the rocks so that the water is enabled easily to pick up and carry away their particles.

A cliff or quarry will show how the rock is thus prepared. Compare the rock from deep in the quarry with that near the surface. Describe carefully the differences observed.

Earthquakes and volcanic eruptions are frequently violent and destructive, making great changes in the appearance of the earth in a few moments; but the work of water is usually carried on

p. 5

FIG. 3.

The sculpturing work of rain-water upon a bank of earth containing boulder-like masses of rock. Klobenstein, near Bogen, Tyrol.

slowly and quietly. Year after year the muddy streams flow down the slopes, removing little by little the material of the higher lands and dropping it upon the lowlands or in the sea.

Which of the warring forces that have been described has gained the advantage at the present time in the case of the Rocky and Sierra Nevada Mountains (Fig. 98)? Which is in the ascendency in the Appalachian

FIG. 4.

New mountain peaks: eroded out of the Kolob Plateau. Temples of the Virgin, Virgin River Canyon, southern Utah.

region (Fig. 5) and the Laurentian highlands of Canada? Which of these systems of mountains do you think is the older? What does the presence of such large and muddy streams as the Missouri, Arkansas, Rio Grande, and Colorado tell us of the future of the Rocky Mountains?

The Result of Conflicting Forces. — All the irregularities of the surface, such as canyons, valleys, plains, table-lands, hills, and mountains, are the result of the struggle between the building-up

and the tearing-down forces. Through all the long time since the solid crust of the earth was formed they have been warring with each other, shaping and reshaping the surface. The region of your home has probably been beneath the sea for long periods. At one time it may have been a desert. At another it may have been occupied by lofty snow-covered mountains or fiery volcanoes.

Fig. 5.

Old mountains. The Presidential Range and Mt. Washington, New Hampshire.

The kinds of rocks which you find beneath the soil, the remains of long-buried animals and plants, and the nature of the streams and land slopes will, if you know how to interpret them, tell you much about this past history.

You will understand more fully as you advance how much the climate, productions, and occupations of the people, in any particular place, depend upon which of the struggling forces has gained the advantage at the present time.

Where is the soil richer, upon the steep mountain slopes, or upon the gentle slopes of the valleys? How do the occupations of the people of mountainous regions differ from those of valleys and plains? In what manner is travel obstructed or favored by mountains, plains, and bodies of water?

The Original Condition of the Earth. — The greatest cold known, a temperature so low that we cannot realize it, is that of space, through whose vast reaches the earth and the planets move and across which comes the twinkling light of the stars.

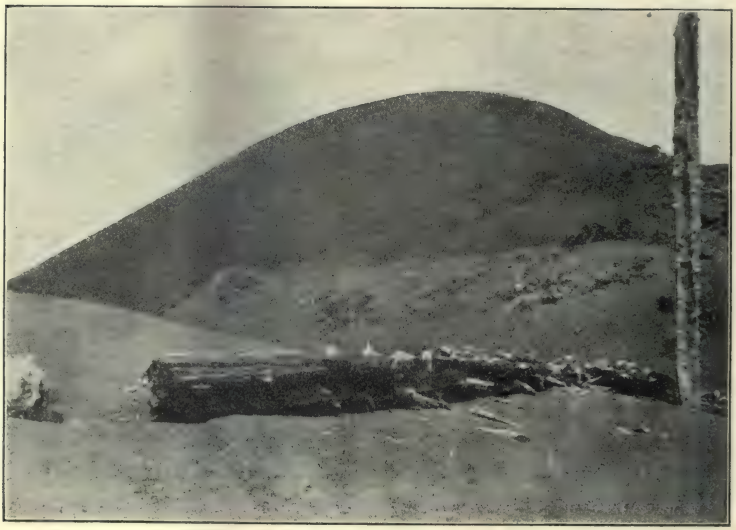

Fig. 6.

Cinder Cone, an extinct volcano. Northern California. The trees were killed by its last eruption, about two hundred years ago.

Why is not the earth as cold as the space about it? Tell what you have observed as to the final temperature of a warm body placed in a cold room. Explain the reasons which we have for believing that the temperature of the outside of the earth is determined by the influence of the sun. If you go down in a deep well or mine, you will find that there is no difference in the temperature between night and day, or winter and summer. What does this fact tell us as to the effect of the sun upon the interior of the earth?

What is the cause of boiling springs and volcanoes? Have they any relation to the sun? What is the meaning of the fact that as we go down in deep mines the temperature gradually becomes higher? Tell from your observations what part of a body cools first, and which cools faster, a large or a small body.

Since the earth is very old and is continually losing heat into space, we must conclude that it was once very much hotter on the

FIG. 7.

Lake of molten lava. Crater of Kilauea, Hawaiian Islands.

outside than it is now, while hot springs and volcanoes tell us that it is still very hot within. These things, together with the wide distribution of rocks that appear to have been formed by fire,[1]

[1] In the eighteenth century, before men had made careful and extended observations of the earth's surface, there arose two schools of geologists. One claimed that the earth was formed through the agency of fire, and the other. that water was chiefly concerned in its making. Now we know that each school had discovered a part of the truth, and that the difference of belief arose from the fact that in one place fire-formed rocks were most prominent, and in another those formed by the action of water.

lead us to believe that far back in the past the earth was a molten, fiery ball, and still earlier it may have consisted of gases in the condition perhaps of the burning vapors which may be seen shooting from the surface of the sun during a solar eclipse.[1]

Experiments indicate that with a sufficiently high temperature all solids can be changed to liquids and these liquids to gases. Describe the

FIG. 8.

The region of the mud volcanoes, Salton Sink, Colorado Desert.

different states in which water occurs. Note the low temperature at which sulphur will melt compared with the melting point of lead. Compare iron and platinum, the latter being infusible in ordinary furnaces. Heat a little piece of sulphur to a high temperature, either in a closed tube or open dish, and note what finally happens.

[1] The generally accepted theory of the origin of the earth is known as the "nebular hypothesis," and with this the following pages are in accord. For a more extended account of the "nebular hypothesis," consult an encyclopedia or good text-book of astronomy. For another view of the origin of the earth, consult Chamberlain and Salisbury's new *Text-book of Geology*.

Describe various observations which you have made as to the effect of changes of temperature upon different bodies. The slow cooling and crusting over of the once molten earth is illustrated in a lava flow, in furnaces, and in the molten lead in the pot of the plumber.

The Early Surface of the Earth. — For a long time after the earth had ceased to glow with heat and had formed a solid crust,

Fig. 9.

The surface of recently cooled lava. Near Flagstaff, Arizona.

it must have still remained too hot for water to stand upon its surface, which may have presented an appearance like that of the bottom of one of the great craters in the Hawaiian Islands (Fig. 7).

Describe the effect of dropping water upon a hot stove. What becomes of the water? What probably was the condition of the atmosphere while the crust of the earth was too hot for water to remain upon its surface?

Fig. 8 may suggest the probable appearance of the earth as the rocks cooled and the water condensed and gathered in the hollows. The

thin crust existing at the time of which we are speaking might be compared to the layer of ice upon a stream, lake, or polar ocean, which is easily broken by the winds, currents, and tides, and piled in low hummocks and ridges. Would you think that the crust at this early period would have been strong enough to support high mountains?

If there were no highlands or deep hollows, what do you think about the probable extent of the land surface then as compared with that of the present day? Would it be quite possible that there was little or no land then? Base your conclusions upon a study of a profile drawing of the present ocean depths and land elevations.

Progress of the Earth towards its Present Condition. — What a change there has been from the world of those early times to the present world, from clouds and mists, water and bare rock (Fig. 9), with no life of any kind, to a sunny world of land and water, of fertile slopes, forests, and grassy plains, all bearing innumerable forms of life.

From this remote period of which we have been speaking until now, the earth has been constantly losing heat by radiation into the cold space about it. The crust has thickened until there remains, in all probability, but little molten material between it and the central portion, which, although certainly hot enough to be molten if on the surface, is believed to be solid because of the enormous pressure upon it.

What effect does changing the temperature of a body have upon its size? What is the object of the blacksmith in heating a tire before placing it upon a wagon wheel? Applying this principle to the earth, what do you think about its size now compared with what it was formerly? Using a specimen of partly dried fruit, explain the cause of the wrinkles upon its surface. Could you compare the interior of the earth as it cools to the pulp of the fruit as it dries and shrinks? Could you compare the mountain ranges of the earth to the wrinkles upon a partly dried apple? Explain fully your reasons for your conclusions.

As wrinkles and ridges appeared upon the earth and continued to grow in size, the dry land increased in area, and the greater part of the water retreated to the hollows, which we now recognize as the ocean basins. There is every reason to believe, as we

shall see later, that the deeper portions of these basins have always been covered with water, and that the backbones of our continents were formed very early in the history of the land.

As soon as the land rose above the water, the rocks began to decay and fall to pieces, as we see them doing to-day (Fig. 10). The

Fig. 10.

The scaling off of a granite boulder, Inyo Range, eastern California.

crumbling was probably more rapid than it is now, for the air was warm and moist and loaded with destructive gases, so that the tearing-down forces found their work easier. The falling rains gathered in streams, which soon began to dig for themselves channels and, out of the rocky earth, to sculpture hills, valleys, and gulches such as we are familiar with. If there had been no water, the surface would resemble that which the moon presents to-day, the mountains being much more lofty and rugged than they are. The Uintah Mountains of Utah, now about two

miles high, would, it is thought, have an elevation of six miles if it had not been for the work of water wearing them down (Fig. 11).

It is believed that living things first began to exist in the shallow water of the oceans, and that they spread from there to

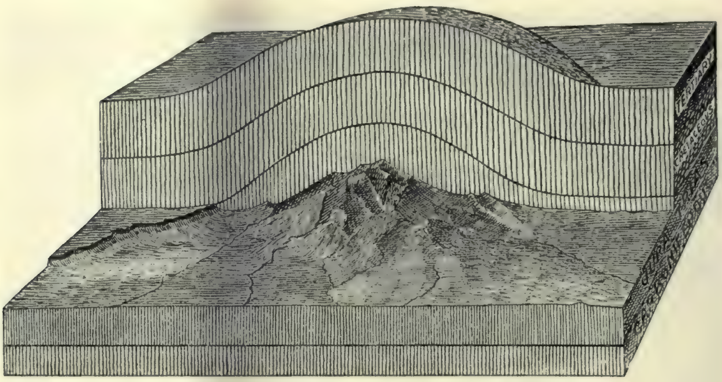

FIG. 11.

Mt. Ellsworth, Utah. The base of the figure represents sea level, the farther half shows result of uplift only, the near half the result of uplift and erosion. (United States Geological Survey.)

the land, becoming more and more diversified as they developed and adapted themselves to new conditions.

Describe some of the water animals now living which spend a portion of their time upon the land.

CHAPTER II.

THE SHAPING OF THE EARTH'S SURFACE — THE INTERIOR OR BUILDING-UP FORCES.

Rising and Sinking of the Land. — Before stopping to inquire into the matter, we would all say that the rock framework of the earth is firm and immovable; and this has been the view held by almost every one until within a few years. The hills and mountains stand just where they did when we first saw them, nor have they changed since our forefathers came to the country. Cities built long ago have not often been put in danger by the rising ocean, nor have they been left far inland by the retreat of the water.

We must remember, however, that the length of time that people have lived upon the earth is very short in comparison with its age. Most of the forces that are at work are so slow in their action that more than a thousand lifetimes would be needed to see mountains worn down to hills, or new ones made where there were none before. A newly quarried block of granite will, in time, crumble to fragments (Fig. 10); but you will not live long enough to see this result, nor probably the slightest indication of it.

The surface of the ocean, which so nearly envelops the earth, forms the great plain from which we measure the heights of the land and the depths of the water. The meeting point of the ocean plain with the land which rises above it forms the shore line.

The waves are leaving the marks of their work along all shore lines. They are either cutting out cliffs or building up sandy beaches. The shore line is the best place to seek for evidence as

to whether the land is sinking or rising at any given place. It is plain that if the land is sinking the water will appear to rise, and that if the land is rising the water will retreat, in each case making new cliffs and beaches.

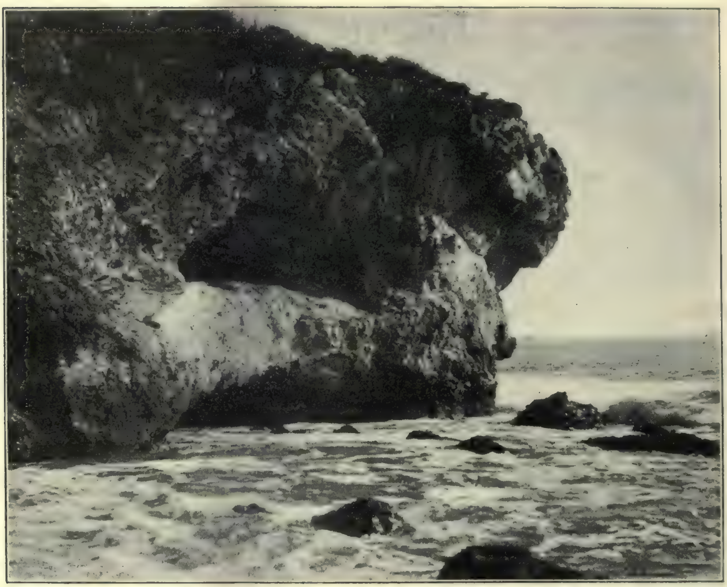

FIG. 12.

Waves undermining cliff and making caves. Coast of California. The upper cave was made at a time when the land stood lower than at present.

Study the action of the waves and currents along any accessible shore and obtain a clear idea of the nature of the shelf which they are cutting in many places. If the ocean or a lake is not within reach, a pond or river may offer opportunities for study.

Describe what the waves are doing in Fig. 12. The upper cave has an elevation of ten feet above the water. If you should climb into it you would find at the rear waterworn pebbles, just like those at the end of the cave which the waves are now making. What does this abandoned cave show as to the movement of the land in recent times?

Explain what is shown in Figs. 13 and 14. Vessels enter this little cove in the fall to load hay and grain. The channel leading into the cove is indicated by the strip of quiet water to the right of the breakers, while still farther to the right, but not shown in

FIG. 13.

A cove formed by sinking of the land and flooding of a stream channel. Coast of California.

the picture, is another line of breakers. This channel, through which the ships come to load at the chute, terminates at the head of the cove opposite the mouth of a little stream. The channel was made by this stream at a time when the land stood higher than it does now, the shore line and mouth of the stream being perhaps half a mile out beyond the present shore. When the land sank, the water swept in, flooding the coastal strip and the channel which the stream had excavated.

One can find far from the present ocean shore other proofs that the land has changed its level. The layers of rock exposed

in the Grand Canyon of the Colorado (Fig. 78), which now have an elevation of more than a mile, are formed of hardened sand and clay which accumulated in the bed of some ancient ocean, just as the same materials are accumulating at the present time.

Determine from a study of the Atlantic and Pacific coasts of North America if there is any relation between the position of the bays and the mouths of the rivers. Give reasons for your conclusions as to whether there have been any recent changes of level along these coasts, basing them upon the facts illustrated by Figs. 13 and 14.

FIG. 14.

Sketch illustrating conditions shown in Fig. 13.

Search in any accessible cliff for rocks formed of hardened sand and clay. Examine them carefully for the remains of animals and plants which lived long ago, and were buried in these rocks while they were still in the form of mud and sand. What does the presence of sea-shells or corals indicate as to the origin of the rocks containing them?

Wrinkling or Folding of the Earth's Crust. — So far we have been speaking merely of the rising or falling of the earth's surface. The upper layers of rock in Fig. 78 are still as flat as they were when beneath the ocean. There are, however, other movements which make great mountain folds upon the surface, and bend the rock layers, so that we find them lying in all sorts of positions.

A local bending of the earth's crust is known as a *fold;* but when the movement is of such a kind as merely to tilt slightly a

large area, perhaps half a continent, we say that this land is *warped*.

Fig. 15 shows a portion of a large fold, several miles across; while in Fig. 16 the folds are small and irregular. Study the latter figure, and determine as closely as you can how much longer one of the crumpled layers would be if it were straightened out. What effect do you suppose the wrinkling of the earth's crust has upon its circumference? Give reasons for your conclusion.

FIG. 15.
Large fold.

It is thought that these folds or wrinkles originate in much the same manner as those upon a baked apple; that is, as a result of the interior becoming smaller. A toy balloon from which the gas has partly escaped will also illustrate the formation of wrinkles upon the earth. Better still is the effect produced by wet-

ting a piece of tissue paper which has been stretched upon a smooth surface. In the eastern and western portions of the United States you will be likely to find the layers of rock, or *strata*, as we usually call them, folded instead of lying flat. In the great central valley, the Mississippi basin, the reverse is the case.

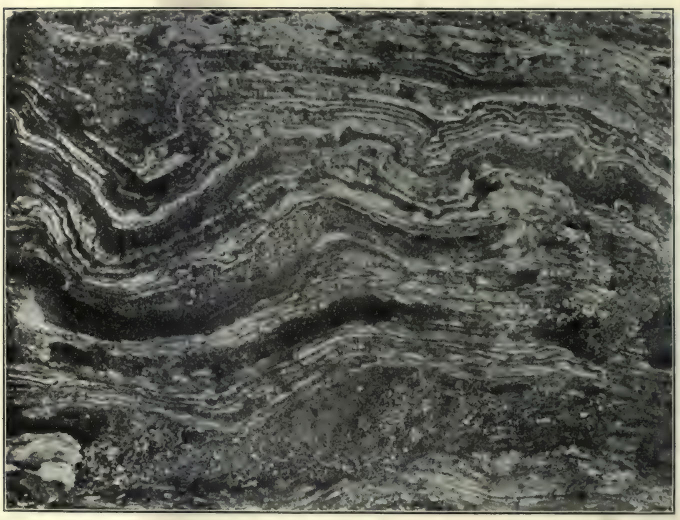

Fig. 16.

Crumpled strata. Point Buchon, California.

What kind of a surface is usually found where the rocks are steeply tilted? Give reasons for your statement. What geographic features would you expect the upward curved portion of a fold to produce? What geographic features would be produced by a downward curved portion? As a matter of fact, the folds are frequently so complex, and have been so worn away by running water, that the slopes of the surface rarely correspond to the dip of the rocks. See if you can find proof of this fact. Make a sketch of any rock exposures which you can find showing the dip of the layers and the slope of the surface.

Where the folding has been very sharp, the layers of rock may have been overturned. You can illustrate this by using a narrow

strip of some thick, heavy cloth which is not too stiff. Lay it upon an even surface and push the ends toward each other. A more elaborate experiment illustrating the folding of rocks can be made by arranging thin layers of different-colored clays in a narrow, box-like receptacle with a glass front. A strong

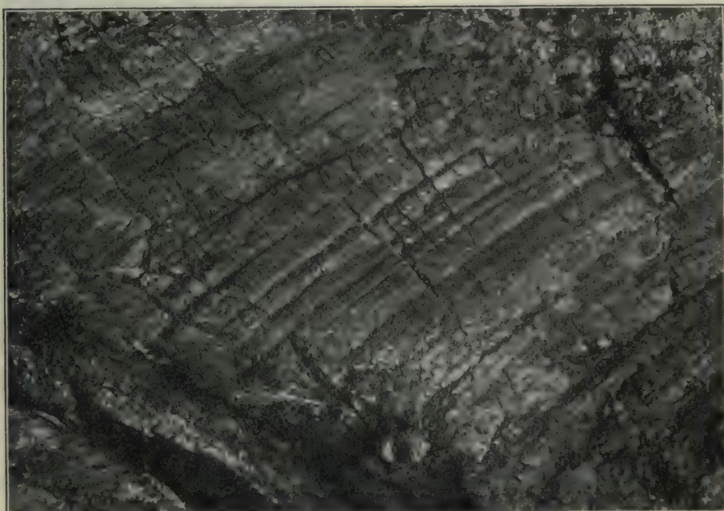

FIG. 17.

Grooved surface of the rocks along a line of fracture and movement. Coast Ranges, California.

pressure applied at one end, which has been left open, will produce some interesting results, which should be sketched.

Fracturing and Faulting of the Rocks. — The rocky strata are broken at times when the crust is subjected to severe strain and the broken ends dropped or pushed past each other. Such fractures are known as *faults*, and are numerous in mountainous regions. As the rocks upon opposite sides of a line of fracture slowly move past each other, there is a grinding and grooving of their surfaces (Fig. 17). In many mines the veins of hard

FIG. 18.

Faulted strata in an ocean cliff. Southern California.

quartz are beautifully polished in this manner. In fact, the movements are at times so severe that the rocks are ground to clay for a distance of several feet upon each side of a fissure.

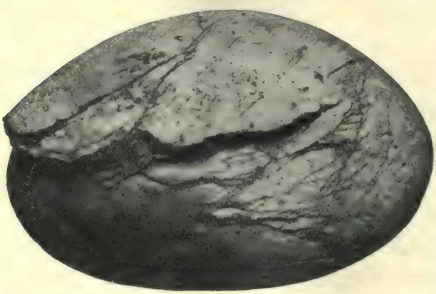

FIG. 19.

A crushed and faulted pebble.

Fig. 18 is that of an ocean cliff and shows distinctly a double fault in rock strata which are almost horizontal. The narrow block in the middle has dropped past those upon the outside. Sketch the broken sandstone layer extending across the middle of the picture and mark the position of the fracture lines.

Fig. 19 shows a beach

pebble of the hardest kind of rock. It was formed long ago upon the shore of an ocean. Afterward it was buried in sand, and hidden deep in the earth's crust, where during the folding of the rocks it was squeezed and pressed so hard that it was faulted and partly crushed.

The movement of the rocks may be no more than a fraction of an inch, as in the case of the pebble in Fig. 19, or it may amount to hundreds or even thousands of feet. The Hurricane Fault of

FIG. 20.

Looking north along the Hurricane Fault. Southern Utah.

southern Utah is one of the most interesting in our country. As the result of a fracturing of the earth such as we have described, and a dropping of the rocks upon one side, a cliff has been formed which varies in height from one thousand to three thousand feet and extends a distance of more than one hundred and fifty miles from north to south. Fig. 20 shows a profile of the cliff looking north from the little Mormon village of Toquerville. The lower plain upon the left was once continuous with the upper one upon

the right. In Fig. 21 we are looking directly at the face of the cliff a few miles north of the preceding view. The dark surface in the foreground of the picture is formed of lava, which was once on a level with the lava appearing in two patches at the top of the cliff. The displacements of the earth's crust which produce such cliffs may occur in a slow and quiet manner; more frequently, however, they are sudden and sharp and give rise to those trem-

Fig. 21.

Front view of the Hurricane Fault.

blings of the earth which we know as *earthquakes.* Some of the most important mountain ranges in the United States have been made in this manner, as we shall see in a later chapter.

A small fault may be produced by taking the mass of clay prepared to illustrate folding, and, after drying it and placing a support an inch or more in thickness under half of it, strike a blow strong enough to break it. The unsupported half will drop down past the other half.

Earthquake Movements. — We have all heard the rattling of the windows accompanying peals of thunder or heavy explosions.

This is produced by the wave-like vibrations of the air which spread in every direction from the point of disturbance in the same manner as do those made upon a pond of water by throwing in a stone. Both the air waves and the water waves strike forcibly against everything lying in their path.

FIG. 22.

Effects of the Charleston earthquake.

Waves or vibrations pass through the earth in the same manner as through the air. The jarring of the ground made by a rapidly moving train illustrates this fact. The rebound of a pebble thrown against a boulder shows that rocks are more or less elastic. Therefore it is not unreasonable to expect that a sudden dropping of the earth along a line of fracture would produce a jarring or vibration distinctly noticeable for hundreds of miles.

The vibration is usually no more than a fraction of an inch, although it may amount to as much as a foot; but it is not so much the size of the rock waves as the intensity of the blow originating them that distinguishes severe earthquakes from gentle ones.

No part of the earth seems free from earthquakes, although by far the greater number occur in regions where mountains are being formed or in the neighborhood of volcanoes. In the case of many earthquakes we shall be obliged to search for a different explanation from that of mountain making, and such is to be found in the conditions which give rise to volcanic eruptions. The latter are almost always accompanied by tremblings of the earth.

From any accessible source gain a clear idea of the destructive effects of the great Charleston earthquake (Fig. 22). A good description is given in the Ninth Annual Report of the United States Geological Survey. Is the region about Charleston a mountainous one, or are there any indications that the earthquake was related to mountain-making fractures in the crust of the earth?

No one yet fully understands all the causes of volcanic eruptions and earthquakes, but it is believed that the shrinking of the earth and the folding and fissuring of the rocks resulting from it are among the initial causes. Rocks are fissured most along mountain axes, and hence in such places the surface water can most readily penetrate the earth. We have learned that far within the earth the heat is intense. Consequently the deeper the water goes the warmer it becomes, and if a considerable quantity should suddenly come in contact with hot or molten rocks the sudden change to steam might produce an explosion which would jar the surrounding rocks more or less severely. The pressure of the steam may find relief through some fissure in the overlying rocks and form a crater-like opening at the surface. The steam frequently brings with it molten rock known as lava, volcanic ashes, of which we shall learn more by and by, and great

quantities of mud, in this manner building up a volcanic mountain. With each renewed accumulation of steam below, an explosion will occur, producing earthquakes and fresh eruptions.

FIG. 23.

Open earthquake fissures. Near Mono Lake, eastern California.

Give some common examples of the force which steam or other gas exerts when it is confined. Which requires the more room, a quart of water or the steam made from it? How much more?

Note upon a map of the western hemisphere the distribution of the mountain ranges and volcanoes. Mountain-making movements are known to be in progress along the western border of North America, and undoubtedly movements opening new fissures in the rocks gave occasion for the eruptions upon the island of Martinique in 1903.

The open fissures in Fig. 23 are the result of an explosion beneath the surface which lifted the rocks bodily and broke them apart. This took place near the shore of Mono Lake at the eastern base of the Sierra Nevada Mountains, — a region marked by many extinct volcanoes, and the scene of several severe earthquakes since the settlement of the West.

FIG. 24.

Lake formed by an earthquake. Near Lone Pine, Owen's Valley, California.

These earthquakes appear to be due, not to volcanic forces, but rather to the slipping of blocks of the earth's crust along lines of fracture having a general northerly and southerly direction. Many of the mountains of the West, including such lofty and picturesque ranges as the Wasatch, with its bold westward scarp, and the Sierra Nevada, with its eastward face, owe their existence to repeated movements of this kind through a long period of time. The lines of the most recent slipping of the earth are plainly visible along the bases of the Sierra Nevada and Wasatch ranges, in

the form of low bluffs or ridges of earth. The formation of each ridge must have been accompanied by a severe earthquake.

The most violent earthquake ever recorded in this region took place in 1872. A gravel bluff, made at the time of this earthquake, is to be seen at many points upon the borders of the valleys lying at the eastern base of the Sierra Nevada Mountains. It is from ten to forty feet high and extends a distance of two hundred miles.

At one point in Owen's Valley the land settled sufficiently to disturb the drainage and form a lake (Fig. 24). The village of Lone Pine, near by, was destroyed and many people were killed or injured. The solid earth was so broken that line fences were rendered crooked. The low embankment just beyond the lake marks the main fissure. The hills lying back of this were raised by similar earthquake movements long ago, while the lofty Sierra in the back of the picture has a like history.

Volcanic Eruptions. — Many of the movements of the earth are so slow that we go about our affairs as though they were not taking place at all, but earthquakes and volcanic eruptions force upon our attention the fact that there are powerful and destructive forces pent up in the earth beneath our feet.

We might divide the causes of volcanic eruptions into two classes. The first has already been referred to in connection with earthquakes. Eruptions due to the formation of steam in the heated regions below are often violently explosive, though it sometimes happens that no lava is thrown out, only a crater-like hole being formed. The crater of Coon Butte in northern Arizona, nearly three fourths of a mile across, must have been made by an explosion of almost inconceivable force (Fig. 217).

The part played by steam in bringing about an eruption is illustrated in the sputtering of a pudding upon a hot fire. If the dish be closed except for a small opening, some of the pudding may be forced out with the steam. A similar phenomenon may be seen in the case of a baking apple when the soft pulp is forced out by the steam through a small opening in the skin.

A second cause of volcanic eruptions is thought to be due to the pressure of the crust upon the molten matter within. As the earth cools and contracts, the weight of the folded and broken crust may squeeze out molten matter where the resistance is the least. Such weak spots are found along mountain axes where the rocks are intersected with numerous fissures.

Now in one place, now in another, throughout the long history of the earth, immense quantities of molten rock have been forced up through fissures and hurled out of the mouths of volcanoes, spreading over thousands of square miles of the surface. The lavas which flooded the northwestern United States and built up the Columbia Plateau were of enormous volume and almost as liquid as water.

Fire-formed Rocks. — Lavas form only a small portion of those rocks of the earth due to the action of heat, for there are many others which have been molten. Among the most common of these rocks are the various kinds of granite, the rock used so much for building purposes.

Study carefully the characteristic differences between a piece of lava and a piece of granite. Compare a piece of one of those rocks with which heat has had nothing to do, such as sandstone, with granite and note carefully the differences.

The lava was formed upon the surface by the cooling of molten rock material which had been forced up from the interior of the earth; while the granite, also once molten, cooled in immense masses thousands of feet below. You will find large areas of granite now exposed upon the surface in almost all mountainous countries. Can you tell why it is more common in such regions than elsewhere? You might answer this question by asking yourself, where are the slopes the steepest and the destructive work of water the most rapid? In mountainous regions the water has worn away thousands of feet of rock strata which once covered the granite, and in this manner rocks have been exposed which otherwise we should not be able to learn much about.

Deeply Buried Rocks. — The effect of the heat and pressure far within the earth is shown by the changes which come over sandstone and other water-formed rocks when they become deeply buried. As the earth's crust wrinkles and fractures, it often happens that rocks once upon the surface are pushed down thousands of feet, or even several miles, into the earth. They may reach a depth where the heat is great enough to melt them entirely, so that on cooling they give rise to real igneous rocks. If they do not reach regions which are hot enough to melt them, they may be, nevertheless, greatly changed. The soft sandstone may become a hard rock called *quartzite*, and the clayey rocks may be turned into *slate*, or possibly into a sparkling rock made up largely of mica scales and called a *schist*.

Hot Springs and Geysers. — After the eruptions have stopped in any particular region and the volcanic mountains have grown cold and lifeless, there still remain for a long time springs of hot or boiling water, telling of the heated rocks not far below the surface. The hot springs of the Yellowstone, of New Zealand, and of Iceland are all in volcanic regions.

There is another class of hot springs, which has no relation to volcanoes, their heat coming from chemical action. Place a piece of quicklime in a little water and note what happens to it, as well as the effect upon the water. The high temperature in some mines is the result of the air coming in contact with and chemically changing the ores.

A geyser differs from an ordinary boiling spring only in being intermittent. In the Yellowstone Park there are some openings in the ground from which steam and water issue continuously with a loud roar. In the case of geysers there must be underground chambers in which the steam collects until its pressure becomes greater than the resistance of the column of water between it and the surface. Then it forces its way violently up through the water, and upon reaching the orifice at the surface the steam and hot water are shot into the air with a dull, roaring sound (Fig. 25).

This eruption continues until the pressure is so lessened that the water again shuts off the steam. The water then sinks back in the basin and into the subterranean chambers below, until the steam again acquires pressure enough to drive it out.

The explosive action of steam accumulating at the bottom of a column of water may be shown by applying a flame to the bottom of a small test tube partly filled with water. Care should be taken to hold the tube so that the water will not be thrown into the face.

The waters of hot springs almost always contain in solution mineral substances that have been taken from the rocks through which they have passed. The presence of carbonic acid gas in the water aids in the solution of many minerals, as also does the heat and pressure in the underground regions. At the surface the pressure is less; the water cools and the gas escapes so that the minerals are there deposited, building up terraces and cones. The deposits in the Yellowstone Park consist in some cases of lime (calcium carbonate) and in others of silicious sinter (a variety of quartz), and have built up terraces and cones of large size and great beauty (Fig. 143).

Fig. 25.

Riverside Geyser, Yellowstone Park. This geyser spouts every six hours.

Give some common illustrations of the greater solubility of substances in hot than in cold water. What mineral does nearly all spring water contain? Mention some of the common minerals in solution in the

waters of mineral springs. Of what particular value are many of these springs?

In some parts of the world, notably in the Colorado Desert, there are springs forming deposits of mud about their orifices. These springs are hot and sulphurous, and probably are the result

FIG. 26.

Mud volcanoes and pot holes. Colorado Desert.

of chemical action. In some cases the mud is carried away underground, leaving basin-shaped depressions; but more frequently cones are built up, some of which are quite symmetrical. The larger cones reach a height of from ten to fifteen feet. The mud is brought up by the gas with which the water is filled, and slowly deposited about the mouths of the springs (Fig. 26).

CHAPTER III.

THE SHAPING OF THE EARTH'S SURFACE — THE EXTERIOR OR TEARING-DOWN FORCES.

The Primitive Surface of the Earth. — We have no certain knowledge of how the first rocks looked; but if the earth has cooled down from a molten condition, as is generally believed, the primitive surface probably resembled that of a recent lava stream (Fig. 9). In this picture the rocks appear rough and jagged, as though they had just become cold. They would make a poor home for any kind of living thing.

There have been so many disturbances of the earth's surface that none of the early rocks remain; but at every new eruption of lava we are supplied with freshly formed rocks for study, so that by comparing lava flows of successive periods we can see the changes wrought by the destructive forces.

What would you think of the comparative ages of the lava flows shown in Figs. 9 and 27? Describe the difference in the character of the surfaces in the two pictures.

Now we want to learn something about the various forces which make the fresh rocks soften and crumble.

Physical and Chemical Forces. — Let us first obtain a clear idea of the difference between physical and chemical changes.

Dissolve a little salt in water and then evaporate the water. Has the salt changed in any way? Heat a piece of iron red-hot, or even melt it, and then let it cool. Is it still anything but iron? These are examples of physical changes. Give other examples of such changes.

Examine a piece of iron that has long been exposed to the air and describe what is taking place upon its surface. Place a bit of silver in some nitric acid and it soon disappears. Evaporate the solution and

determine if what remains is silver or another substance. These last examples illustrate chemical changes. Give other illustrations.

A physical change is one of appearance merely; a chemical change is one in composition. Chemical and physical forces supplement each other in their destructive work, so that it is often impossible to distinguish them.

FIG. 27.

Surface of a lava flow. Southern Oregon.

Water and carbonic acid are the chief forces that we want to talk about; and though their operations are usually carried on very slowly, yet in the course of time they accomplish great results.

Pure water has very little solvent action upon the minerals composing the rocks; but all water contains more or less carbonic acid, which greatly increases its power in this regard. The air is continually supplied with carbonic acid from chemical changes taking place upon the earth, and the rain, falling through the air, absorbs more or less of this gas, of which it makes use as it percolates through the rocks.

What is the gas of soda water fountains? Find out and illustrate how it is made.

The rain water containing carbonic acid gas gathers in the hollows of the rocks and soaks into the crevices, dissolving some of the mineral matter and loosening the hold of the little grains upon each other. It is the firm grip that the grains of a fresh rock have upon each other which distinguishes such a rock from

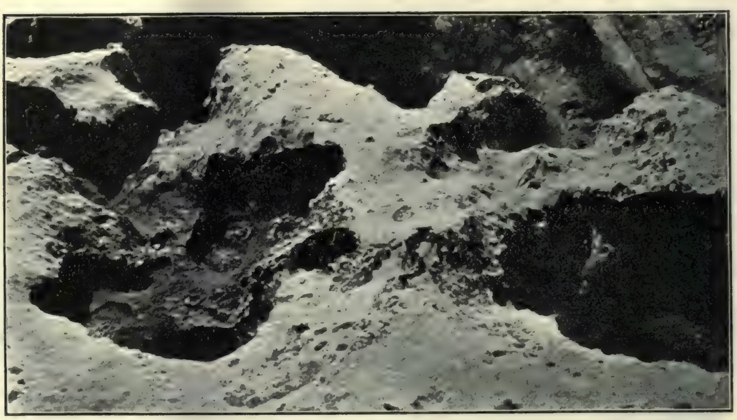

Fig. 28.

Pitted surface of limestone resulting from solution by rain-water. Arizona.

a decomposed and crumbling one, as you can see by comparing a piece of weather-beaten granite with one fresh from the quarry.

The chief substances which are dissolved by water containing carbonic acid are the compounds of lime, of iron, of magnesia, of soda, and of potassium. All spring water contains lime in solution, and if there is a large amount of carbonic acid, as in the case of "soda springs," many other minerals are usually found in the water. The presence of these minerals is shown by deposits about the orifices of the springs, and some of the minerals — iron, for example — are noticeable even when present in very small quantities.

Why are the springs referred to called "soda springs"? How would you show the presence of minerals in spring water? What is the source of the deposits which form in teakettles? Obtain, if possible, a piece of such deposit and moisten it with a drop of some weak acid. Describe what takes place. Tell what mineral is indicated.

The solvent power of water is particularly noticeable in limestone regions, where enormous caves are frequently hollowed out

FIG. 29.

Stalactites in a limestone cavern. Canyon of the Colorado River.

of the solid rock. The pits upon the limestone in Fig. 28 have been formed through the solvent action of rainwater collecting in slight hollows. The water, percolating down through crevices of limestone formations, gradually removes particles of the lime until caverns are formed. Water containing lime, dripping from the roofs of such caverns, deposits icicle-like columns (called *stalactites*), which are often very beautiful (Fig. 29).

FIG. 30.

A cliff of granite intersected by vertical seams. Summit of Sierra Nevada Mountains, overlooking Owen's Lake, California.

The soft clayey rocks of delta regions and those of the beds of dry lakes often contain so much soluble material, such as salt and alkali, that the water of the streams and springs is hardly fit to drink. How can you show the presence of these substances in water?

The mineral components of nearly all rocks contain lime, but you cannot easily detect it until the rocks have begun to decay.

Fig. 31.

Weathering of lava. Dry Coulée, Washington.

Using specimens of the same rock, one fresh and the other somewhat decayed, test for lime by means of a few drops of dilute hydrochloric acid. Watch for any effervescence and examine carefully the specimen which shows it. The appearance of minute bubbles tells us that the acid is attacking the lime and forming carbonic acid gas.

No matter how firm and solid the rocks appear to be, water slowly penetrates them. Minerals not directly soluble become

changed by absorbing water. When exposed in this condition, they are easily attacked by the air, and at last, when completely decayed, crumble to a clayey mass.

Water has penetrated the solid rocks to a great depth, as can be shown by taking a piece of rock from the bottom of a

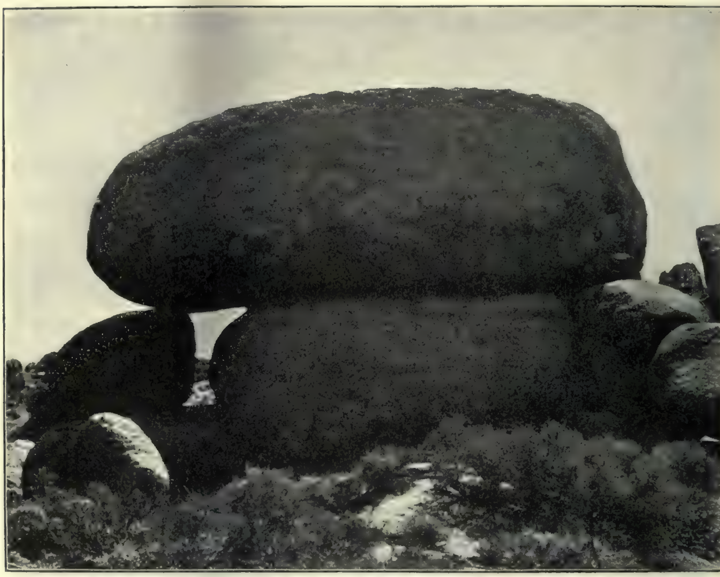

FIG. 32.

Granite boulders, result of weathering. Inyo Range, California.

quarry or mine, and, after weighing it carefully, drying it in an oven and then weighing it again.

The water absorbed into the rocks prepares them for the work of oxygen, that active life-giving constituent of the air. Oxygen does not, however, carry on its work to a depth of more than a few inches. In the presence of water it softens and decomposes the minerals exposed to its attack, producing the stains which we see upon the surface of rocks. In a piece of granite, for example,

the mica loses its bright luster and elasticity; the dark hornblende crystals soften and turn greenish; the feldspar whitens and begins to turn into kaolin. The quartz grains alone, of all the constituents, remain unaffected, although they finally fall out of the rock and collect as sand. The iron present in the form of little grains, and also as a part of the mica and hornblende, gives the reddish or yellowish stains which mark the whole mass.

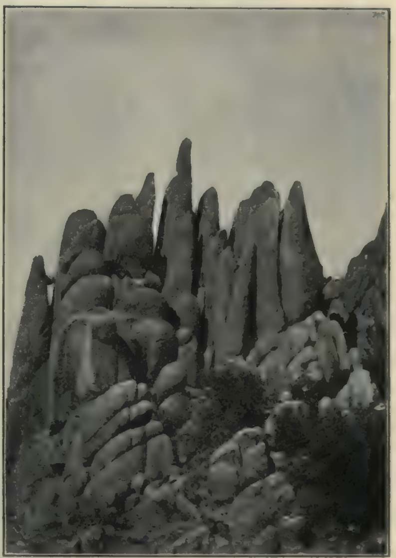

FIG. 33.

Granite Needles. Near Prescott, Arizona.

Examine any cliff in your neighborhood for evidences of rock decay. Compare the appearance of rock long exposed to the air with that recently uncovered at the bottom of the cliff. Note the relative coherence of the particles of fresh and decayed rock. If there are seams in the rock at the top of the cliff, trace them downward and find out what becomes of them. Break open pieces of rock and boulders that have been long exposed to the air and observe if there is any difference between the center and the outside.

Describe Fig. 30. Does the direction of the seams have any relation to the steepness of the cliff?

Influence of Living Things. — Living things have more to do than is commonly supposed in aiding the work of destruction going on upon the earth's surface. The crumbling rocks, as well as the soil, are filled with a multitude of microscopic organisms known as *bacteria*. They play an important part in the change of the insoluble mineral particles into others which are soluble in water.

There are also the earthworms, the moles, the squirrels, and the ants (Figs. 88 and 89), which make their homes in the earth and aid both mechanically and chemically in the breaking up of the rocks, and in bringing the fragments to the surface where the air can get at them.

Describe from observation the work of these organisms.

FIG. 34.

Rocks held in roots of a fallen tree. Yosemite Valley, California.

Mechanical Agents. — There are agents of a purely mechanical nature, which work in harmony with the chemical ones. Each aids the other in breaking down the rocky surface.

First among these forces may be mentioned heat and cold. The changes of temperature to which rocks are subjected are an important factor in their disintegration. During the heat of the day the mineral particles or grains composing them expand a little and press more tightly upon each other. With the lower

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FIG. 35.

Talus Slope, back of the great rock slide in the canyon of the Columbia, above Wenatchee, Washington. The leaning of the trees is due to recent movement of the slide. The whole slide is shown in Fig. 38.

temperature of night they contract. This process, repeated day after day, causes them to lose their firm hold upon one another. Water penetrates more easily into the minute fissures thus formed and aids the decay. In a piece of fresh rock the minerals are attached to each other so firmly that they will break before they will separate from each other; but a decomposed piece can sometimes be crushed in the hand. Dry Coulée, Washington, is a canyon occupied by the Columbia River during the Glacial period, but now abandoned (Fig. 31). The slopes of broken rock in the foreground have all been formed by the crumbling of the lava cliffs under the influence of heat and cold in the few thousand years since the river excavated the canyon.

FIG. 36.

Creep of soil down a hillside.

Give some illustrations of the change in the size of bodies as the result of heat or of cold. What must be the effect of the freezing of water that has penetrated the seams in rocks? Explain how freezing and thawing would affect the crumbling of the cliff in Fig. 30. What time of the year is this destructive action the most rapid? Describe the effect of freezing and thawing upon moist ground. Give some common illustrations of the force exerted by freezing water.

Many rocks, such as granite, scale off as a result of changes in temperature. The formation of scales begins at the corners of the blocks and continues until they are reduced to boulder-like masses (Fig. 32).

Explain the phenomena shown in Fig. 10, which represents the under side of a huge mass of granite. Point out the reasons for the peculiarities of the weathering in Fig. 32. What becomes of the waste

from the decay of the rocks in the latter figure? In what way does the presence of seams in Fig. 33 facilitate the decay? How far is it likely that these seams extend into the earth?

Explain in detail, as a result of your observations, how the roots of plants aid mechanically in the breaking down of cliffs and the crumbling of rocks. Give an illustration of the power of the roots of growing trees. When a tree falls, its roots frequently pick up and hold in their

Fig. 37.

Landslide near Wardner, Idaho.

grasp large quantities of earth and rock. In this manner material buried several feet deep in the soil is exposed more directly to changing temperature, to oxygen, and to other destructive forces (Fig. 34).

Talus Slopes. — A very important agent, always present, and without which, indeed, there would be little wearing down of the earth's surface, is the force of gravity. If it were not for the

force of gravity, giving everything weight, water could not do its work, and the elevation of the land and the steepness of the mountain walls would exceed anything we know.

Gravity has no effect upon solid rock held firmly in place; but as soon as water, air, and plants have sufficiently loosened exposed portions of a cliff, the pieces fall from their places and roll as far as their momentum will carry them. Thus rock fragments are continually accumulating at the base of cliffs. In the

FIG. 38.

Rock slide in canyon of the Columbia River, Washington.

course of time the mass of débris will so increase in quantity that the cliff itself will be entirely buried beneath its own waste. Such a mass of débris is termed *talus,* and the slope which it assumes is known as a *talus slope* (Fig. 35).

Make observations upon any accessible slope of this kind, and determine about what its inclination is in degrees. Upon what part of a talus slope are the fragments the largest? Which acquires the greater momentum and moves the farther, a small or a large fragment? Upon

what portion of a talus slope will soil and vegetation gather first? Examine stream banks or cliffs in different portions of your neighborhood so as to discover what kinds of rock decay and build up talus slopes most rapidly.

Examine carefully some stream bed in which there are pebbles, and find out, if possible, what part gravity plays in their movement down stream. Will boulders move down a hillside which is not steep enough for them to roll down?

FIG. 39.

Scene in northern Coast Ranges, California. Note the effects of landslides, of erosion, and of the tramping of cattle.

The Creep of Soil. — Examine the fences upon any hillside and note if they show a tendency to lean, as does the fence in Fig. 36. If the fences do lean, is it up hill or down hill, and what is the cause? Which way will the particles of soil upon a hillside move by their weight? Observe carefully what effect the freezing and thawing, the tramping of animals, and the cultivation of the surface have on the soil and rock fragments upon a slope. It has been estimated that the creep of soil

down a hillside, such as is shown in Fig. 36, may amount to as much as one foot in ten years. Will the particles at the top or bottom of the layer of soil move the faster? What effect would this naturally have upon a fence originally upright?

Landslides. — It frequently happens that upon steep slopes the soil and rocks become so loosened over a considerable area that they are carried down by their weight in one huge broken mass.

Fig. 40.

Paths of avalanches in the San Juan Range, Colorado.

The starting of a *landslide* is commonly due to heavy rains, which, sinking deep into the crevices and seams, loosen the soil and rocks so that a portion breaks away. When the seams slope toward the lowland and are slippery from the presence of clay, a landslide is greatly facilitated. Landslides may occur upon very gentle slopes, if there are large bodies of water-soaked soil resting upon slippery surfaces. Among mountains landslides are frequently very destructive, sweeping away villages and farms.

A landslide into a lake in Norway in the winter of 1905 caused the death of fifty-nine persons, through the great waves which it produced. Slides also occur along seacoasts as a result of undermining by the waves, and in steep-walled canyons as a result of similar action by running water (Fig. 37).

One of the most interesting rock slides known in the United States took place in the canyon of the Columbia above Wenatchee.

FIG. 41.

Tunnel through an avalanche, above Ouray, Colorado.

At this place a great body of granitic rock broke away from a cliff nearly one thousand feet high and plunged down into the Columbia River. The slide was three fourths of a mile long and one thousand feet wide (Fig. 38). It took place about one hundred years ago, if we can judge from the age of the trees growing upon it; but others have occurred in very recent times, and the whole mass is still moving, as shown by the leaning of the trees (Fig. 35).

Study Fig. 39 closely and distinguish the work of the different agents which have aided in producing the features of this landscape.

If there are any steep slopes near your home, seek for the presence of little slides of soil. These are much more numerous than the large slides. What is the cause of slides along railroads and wagon roads in wet weather? About what degree of slope does nature usually insist upon before she will cease producing landslides?

Avalanches. — The destruction wrought by avalanches after heavy snowfalls in the Rocky Mountains is frequently mentioned in the newspapers during the winter and early spring. The accumulation of snow on a steep slope may become so great that it begins to move. Increasing in volume and velocity, the mass finally acquires irresistible force and sweeps away the rocks, trees, and buildings in its path, leaving a plainly marked trail (Fig. 40). In the spring of 1902 an avalanche filled a canyon above Ouray, on the Silverton road, Colorado. In order to reach the mines above, a tunnel had to be made through the solid icy mass (Fig. 41).

Find, if you can, descriptions of some of the avalanches in the Alps.

CHAPTER IV.

THE EXTERIOR OR TEARING-DOWN FORCES. — Continued.

Introduction. — If the destructive forces which we studied in the last chapter were the only ones at work upon the earth's surface, the solid rocks would after a time be completely buried under a mass of their own fragments. Granite, for example, decays to a depth of many feet, becoming so soft that it can be removed with a pick and shovel. The road shown in Fig. 42 has been worn deep into such a mass of granite. The feldspar grains of the once firm rock have turned to clay, the mica scales have softened, and the quartz grains have become loosened, so that now the whole superficial portion of the granite is in a condition to be easily removed by water.

Why, in the case of the figure just referred to, has erosion removed the decomposed granite from the road more rapidly than from the surrounding surface?

This process of decay under the influence of atmospheric agencies we call *weathering*, and it goes on most rapidly at the surface. If the softened rock particles are not removed, the layer of waste becomes thicker and thicker and at last forms such a protecting covering that rock decay becomes exceedingly slow.

The land surface of the earth, with the exception of those parts covered with recent volcanic materials, has long been exposed to weathering. It might naturally be supposed, then, that the rocky crust would everywhere be so deeply covered with its own waste that it would be completely hidden. This, as we all know, is not the case. In hilly and mountainous regions, in the sides of creek channels, and in sea cliffs the solid rocks appear.

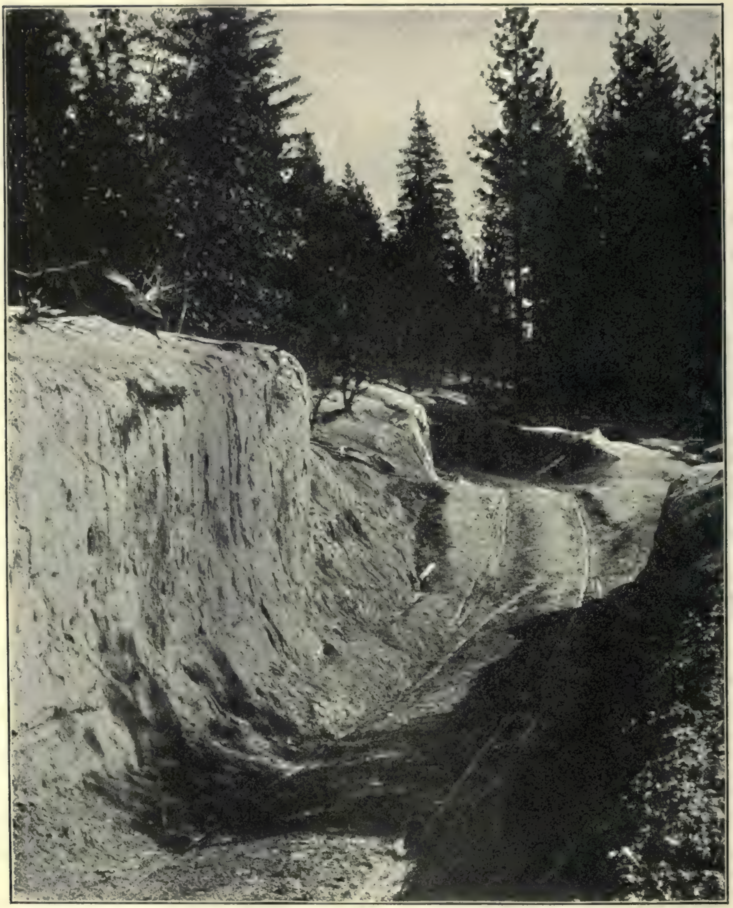

FIG. 42.

Road worn deep in disintegrated granite of Sierra Nevada Mountains.

In the present chapter we want to find out what those agents or forces are which are removing the waste and keeping the rocks exposed, and how they do their work.

Denudation. — The loose and waste rock fragments are con-

stantly being removed from all the higher and more exposed portions of the land and are either dropped upon the lowlands or carried to the oceans. This process, which tends to lay bare the rocks, is called *denudation.* The agents concerned in this work are running water, waves, glaciers, and winds. Running water is by far the most important, and that will be taken up first.

Is the work carried on more rapidly upon steep or upon gentle slopes? Which of the agents mentioned are not affected by slope? Which of these agents work most rapidly in mountain regions? Give illustrations, from some of your observations, of the work of each of the agents.

The Work of Running Water. — Water under the pull of gravity seeks the lowest place it can find. Wherever it rains and little rills form, there water begins its work of denudation, or *erosion,* as it is often called (Fig. 43). The accumulating raindrops form rivulets, and these, moving down the slopes, pick up or roll along the minute particles of rock waste. The tiny streams unite into larger ones, and these, as long as the current is swift, are able to move still larger fragments of rock. At last all the branch streams of a watershed unite in one trunk stream. By this time the water has reached the main valley, and the slowly moving current begins to drop the larger fragments. Only the finest particles, to which we give the name of *silt,* continue on toward the mouth of the stream. A part of this material may finally be spread over the lowlands during periods of flood, and a part dropped in the ocean or lake into which the stream empties.

Explain why it is that after a heavy rain some streams become very muddy, while others remain comparatively clear. What other factors besides slope of the land affect the work of water? Do all rocks crumble and decay with equal ease? Examine any resistant masses of rock which you can find projecting up through the soil and note if they are different from the rocks over which a layer of waste or soil is formed.

Observe the character of the water running from a field of plowed land and compare it with water flowing from grass-covered slopes. Have you observed any connection between the position of newly formed gullies and old trails, cow paths, or abandoned wagon roads? What kind

of material is carried away by the streamlets most readily? Determine this point by obtaining some muddy water and examining the sediment which will finally collect in the bottom of the dish. What would you

FIG. 43.

The sculpturing work of rain-water upon a cliff of soft sandstone. Coast Ranges, California.

conclude as to the relative rapidity of erosion of clayey and sandy rocks?

What determines the position of the rills which you have observed

gullying a hillside? To what extent were their channels ready formed? Compare the effect of two streams upon a hillside of solid rock, if one of the streams has clear water and the other is loaded with silt and sand. Compare the work of the same streams upon a hillside of soft decomposed rock. The tools with which the water works and with which it has excavated the deepest canyons are the particles of rock which it rolls and pushes along the bottom, thus grinding away even the hardest and firmest rocks.

FIG. 44.

The effect of the rains upon an unprotected surface in the semi-arid region.

A mountain range (Fig. 212) is, as we have seen, the work of the internal earth forces. Its individual peaks, cliffs, and canyons have been sculptured out of the solid rocks through the action of various destructive forces. Chief of these is running water, which, with its load of sand, gravel, and boulders, is continually wearing away the bed rock, thus deepening the channels of the

streams. In cold latitudes and in mountainous regions ice has also played a part in this work. The weathering and disintegration of the rocks greatly facilitates erosion, which, aided by the presence of seams and joints, gives the distinguishing features to many mountains.

If, then, we take a relief model, representing one of the earlier periods in the history of a mountain range, and fill in the gulches, canyons, and valleys with some soft substance, we shall obtain a surface bearing a considerable resemblance to that upon which the water first began to flow.

Explain the various features in Fig. 44. Make a sketch of the manner in which some stream with which you are familiar divides toward its head. As the rocks of a hill or mountain slowly crumble and are carried away, will the rate of denudation finally be affected? When will denudation stop? If the rainfall is light, how will this fact affect the removal of rock waste? What, then, might be expected to be the character of the mountain slopes in dry regions?

Stream Action. — Obtain from some creek bed well-rounded pebbles and describe their origin. Examine a small wet weather stream during and after a rain and prepare a carefully written description of the changes that take place in its channel.

Measure the flow of some stream; that is, determine the amount of water which passes a given point in a second. You can obtain the velocity of the current by throwing something upon the surface of the water and noting how long it takes for the object to be carried a certain distance. At the same place, obtain the width and average depth of the water. Now you can compute how much water passes in a given time. At flood time dip up a measured amount of water and either evaporate it or let it stand and settle, so as to obtain the sediment which it contains. Now you can obtain the proportion of sediment by weight or by volume. Silt is about two and one half times heavier than water. The most reliable method is first to weigh the water carefully and then evaporate it. Would you obtain all the materials carried in solution by letting the sediment settle and then pouring off the water?

Why is it that streams flow in irregular curving channels? Are curves more numerous in rapid or slow streams? Which side of a curve is likely to be shallow and contain bars? Explain the conditions which gave rise to the bar in Fig. 45. Which way is the river flowing?

Why are the bottoms of the little gulches so even, in Fig. 44? If dikes of hard rock lay in their courses, what would have been the result? If possible, examine a rapid or waterfall in your neighborhood, and find out definitely the causes which have produced it.

Transportation and Deposition of Rock Waste. — A large stream, other things being equal, will transport more material than a small one, and a swift stream more than one with a sluggish current. Besides volume of water and slope of channel, the

FIG. 45.
The Columbia River, Washington.

amount of waste or crumbled rock brought to a stream has a very important effect upon its behavior. A stream flowing at a gentle grade will, if it is carrying but little waste, keep its channel clear and possibly deepen it; but if it is overloaded with clay, sand, or coarser material, this will be dropped in its lower reaches where the current becomes more sluggish. Indeed, so much waste may be brought to the stream that it will, even in its middle and upper course where it is flowing swiftly, fill up its channel instead of deepening it.

The point of adjustment between the amount of water, grade, and load which a stream will carry is a very delicate one.

This fact you can readily observe in the case of a wet weather stream flowing over an easily eroded surface. Fig. 46 shows a valley whose even surface has recently been overspread with gravel and pebbles. In the center is a small stream flowing along quietly in a shallow trench.

Fig. 46.

A valley in the Coast Ranges of California.

Explain the conditions under which the gravels were deposited, and the trench excavated by the stream.

Fig. 47 is that of a narrow valley in a very dry region. The rocks adjoining the valley are granite. Explain the conditions which have led to this valley gradually filling up with sand. Why does not the water which evidently flows here during a part of the year carry away the sand?

Will a stream do more work when confined between narrow banks or when spread out? What is the object of building jetties at the mouths

of streams, as, for example, in the South Pass of the Mississippi River? How are the mouths of harbors sometimes deepened?

Many Western streams, such as the Platte and the Rio Grande, carry so much silt and possess so slight a grade that they flow through broad flood plains with very low banks. In taking the water from the Rio Grande for irrigation, the ditches have

FIG. 47.
A gulch near Riverside, California.

to be dug so that their beds are inclined at a little less slope than the river. As a result the muddy water deposits silt so rapidly that they have to be cleaned out at least once a year. The old ditches thus become raised above the level of the valley and their banks form great dikes (Fig. 48).

The bottom lands along the middle and lower courses of nearly all streams are occasionally flooded after a period of heavy rain or rapidly melting snow. The water of the widely spreading flood, more quiet than that of the narrow stream, drops

its silt; and after the flood has subsided, a layer of mud is found over everything.

Bring proofs of this statement from the examination of some pond of muddy water which is drying up, or from a recently flooded lowland.

If there are any alluvial bottom lands in your vicinity, examine the trenches which the streams make in them. Note the character of the material. Compare it with that upon the upland slopes. Can you detect any indications of the successive layers by the addition of which it was built up?

Fig. 48.
Irrigating ditch near Albuquerque, New Mexico.

The irrigating ditches recently referred to illustrate another interesting fact about rivers, and this is that their channels across the lowlands may be so raised by the accumulation of silt that their beds are above the level of the adjoining country.

Disastrous floods occur whenever the banks are broken, driving the farmers from the fertile fields.

Mention any river that you know of which forms floods of this kind. What effect does the disturbing of the surface of the land by man have upon the silting up of stream channels? Which will furnish silt faster, a bare surface or one covered with vegetation? If solid rock outcrops upon the sides of a valley, and wells sunk upon its level bottom encounter no such bed rock, what explanation would you give for the fact?

The broad plains about the mouths of the great rivers of the world have been formed, through the course of many long years, as a result of deposition of silt at flood time. This material, fine and rich, productive of the most luxuriant vegetation under the influence of warmth and moisture, is sometimes more than one thousand feet thick. It represents, however, only a part of the material of the rocks which once rose in rugged mountains about the heads of the rivers. The larger part of the waste of the mountains has been borne beyond the plains and dropped in the lake or ocean into which the waters empty. Here it has been spread out by the currents, in this manner building up plains beneath the water, very similar to the flood plains of the land.

With regard to stream denudation and deposition, we may divide the land into three parts. There are, first, the high and steep slopes where denudation is more rapid than rock decay. Here the rocks are bold and picturesque, rising in jagged peaks and precipitous crags. Below the rugged mountains there are the gentler slopes, where rock decay is in most places more rapid than denudation. Here the rocks are generally hidden beneath a mantle of waste, and the hills are rounded in outline. Lowest of all are the plains of accumulation, built up from the waste of the highlands. The solid bed rock of the upper slopes is here entirely hidden and may be so deeply buried that it is not reached in the deepest wells.

Unless there should come a disturbance of the earth's crust, interrupting the process, the lowland plains will continue to build

up and encroach upon the mountains until the latter are separated into detached peaks and ridges, and finally reduced to sloping hills. Excellent examples of this process are presented by many of the mountains of the Great Basin, which rise island-like from the vast desert plains (Fig. 308).

As the slopes of the land become more gradual and denudation decreases, the mantle of decayed rock and waste grows ever deeper and more extensive, until it covers everything, the plains of accumulation being scarcely distinguished from those of erosion.

Wave Erosion. — The work done by the waves in wearing away the land and distributing the waste is next in importance to that of running water. The more extensive the body of water, the larger are the waves which the wind raises upon its surface and the more important the work done by them.

Along exposed portions of shore lines the waves are continually washing away the mantle of loose rock material and eating their way into the solid crust. A portion of the waste is distributed over the adjoining floor of the lake or ocean. Another portion is sorted out and piled in bars and beaches along more protected shores. The waves strike fierce blows, but have no more erosive power than clear running water. They sweep off the soil and loosened rock particles, but without assistance they would have little effect upon the firm cliffs. The tools which they use are the fragments which have fallen from the cliffs and lie strewn along their base. With every wave these are hurled against the shore, slowly wearing it away; while the fragments themselves are rounded to pebbles, and, if thrown about long enough, are reduced to sand.

If possible, visit the shore of some body of water during a storm and observe carefully the manner in which the waves attack the cliffs. Note the dull rumble of the pebbles as they move back and forth, grinding upon each other and upon the bottom. Observe at what points cliffs appear, and if the ruggedness of the cliffs is in any way related to the hardness of the rocks. Observe also the distribution of the beaches, both of sand and pebbles, and account for this distribution.

If the rock in a cliff is very resistant to weathering (those atmospheric influences described in the previous chapter), the waves will undermine it until, parting along some seam, a huge mass breaks off. The fragments thus formed constitute new weapons for the waves and are in turn reduced to boulders and pebbles.

Turn to Fig. 12 and tell whether wave action or atmospheric disintegration is more rapid. Give your reasons. The lower cave in this illustration is exposed when the tide is out and is shown in Fig. 49. Describe the part played by the pebbles in deepening the cave.

Fig. 49.

The back end of a wave-worn cave.

Where the rocks disintegrate rapidly, the cliffs are not likely to be precipitous, and the waves dash up over them instead of against their bases. Upon the border of a sinking land the shores are almost certain to be marked by cliffs, unless the land

is very low (Fig. 50). There is no opportunity for a protecting fringe of sand or boulders to collect at the base of the cliffs, and as a result the waves expend all their force against the rocks.

If a land is rising or has stood at the same level for a long time, extensive beaches will appear. As these continue to grow the waves are, little by little, shut off from the cliffs. The latter

Fig. 50.
Wave erosion at Point Buchon, California.

crumble and lose their precipitous character, finally becoming covered with soil and vegetation.

The waves accomplish most at high tide and during storms.

Call to mind anything that you have read about the destructive effects of storm waves when they occur in connection with high tides. Note the discoloration of the water during stormy weather. How far out from shore is the waste from the land sometimes carried?

Compare the bottom of any body of water to which you have access with the surface of the land adjoining and tell the difference. Find out all you can about the shores of the North Sea, especially those of England and Holland, and the causes of their peculiarities.

The island of Helgoland in the North Sea contained an area of one hundred and twenty square miles in the year 800 of our era. In 1300 the waves had reduced it to forty-five square miles, in 1649 to four square miles, and at present there is left only one third of a square mile of surface (Fig. 51). During historic times the land about the borders of the North Sea is

FIG. 51.
The island of Helgoland, North Sea.

known to have subsided, and this has greatly facilitated the destructive work of the waves.

Glacial Erosion. — Wherever it is too cold for the snows of one winter to melt completely before the coming of those of the succeeding winter, there will be formed a permanent snow-field. With the alternate thawing and freezing of day and night, the snow grows harder and more compact until at last it turns to a solid mass of ice. This ice does not behave like an ordinary solid,

which keeps its shape and remains in one place as long as it is undisturbed. The most familiar object to which we can compare glacial ice is hard molasses candy. The candy appears to be brittle if struck a hard blow, but if subjected to a gentle pressure, even of its own weight, it bends and adapts itself to the irregularities of any surface upon which it may be lying.

A mass of icy snow, whether it lies in a basin high up on the mountains or upon some broad, gentle slope, will under the pull of gravity, aided by freezing and thawing, move downwards, but its movement can usually be detected only by days or weeks of careful observation. The slowly moving ice stream will continue its course down the slope which offers the easiest path, until it reaches a region where the heat is great enough to melt away the lower end as fast as it advances.

Every year the glacier is fed anew at its source by falling snow, while at the lower end the melting of the ice forms a perennial stream of milky water. This color is given to the water by the fine particles ground from the underlying rocks by the moving ice. The glacier accommodates itself to the uneven surface, partly by bending and partly by breaking, so that it becomes intersected by innumerable fissures (Fig. 52).

In the tropics glaciers are now found only upon the very highest mountains. They once swept down into the temperate latitudes from the polar regions and in some cases were thick enough almost to bury mountains. At present, however, they are found only on the high mountains of these latitudes. In the polar regions glaciers are still numerous and often cover a great extent of surface even at the level of the sea. Where they descend to the sea they furnish the material for icebergs (Fig. 53).

A glacier resembles a stream of water, in carrying away the particles of soil and fragments of loose rock, as well as in its power to excavate a channel for itself. Unlike water, however, it bears along bodily huge masses of rock which have either been torn from its channel by the moving ice or have fallen upon its

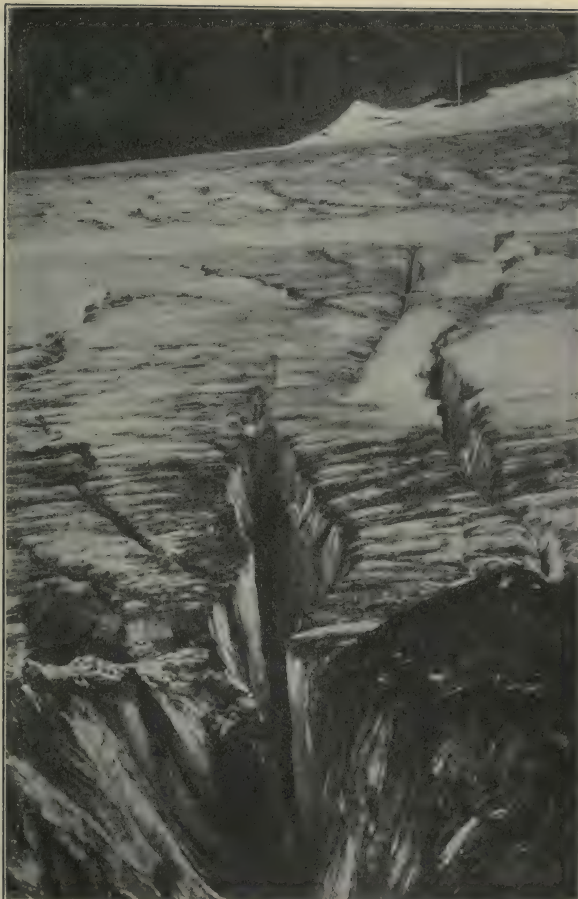

FIG. 52.

Glacier upon the Three Sisters, Oregon. Note the boulders ready to fall into the crevasse and thus reach the bottom of the glacier. They form the tools with which the glacier grinds away the bed rock.

surface. These rock masses of varying size become embedded in the glacier and are held firmly by it. Wherever they come in contact with the bed rock they slowly grind it away, and are in

turn ground and polished, as is the piece of crystal which a lapidary holds against a revolving wheel. If the rock is hard, the surface over which the glacier passes is beautifully polished and grooved, the markings being retained for hundreds and even thousands of years after the disappearance of the ice.

If bold cliffs rise along the borders of a glacier, its surface becomes more or less covered with fallen rocks. This surface load

FIG. 53.

Taku Inlet Glacier, Alaska. The front of the glacier is 100 to 200 feet high and is constantly breaking off and forming icebergs.

is borne along in company with the fragments torn from the bed of the glacier, and all are dropped at its lower end. A part of this rock waste is piled in peculiar hummocks and ridges, as we shall see later, and a part is swept away by the muddy stream which flows from beneath the end of the glacier.

What condition of the surface facilitates the preservation of glacial scratches? Compare pebbles, which you can obtain from any creek or beach, with the glacier-cut pebble in Fig. 54 and give a careful description of the differences. How much effect would a glacier have upon its bed if it carried no rock fragments?

FIG. 54.

Pebble grooved and polished by a glacier.

If your home is in the northern United States, you will be able to learn from your own observations something of the vast amount of destructive work accomplished by the great continental glacier which once spread over that part of the country.

FIG. 55.

Work of the drifting sand upon the plains of Wyoming.

Note the stray boulders which occur almost everywhere and compare them with the rock in place, or *bed rock* as it is commonly called. Where the bed rock is hard you will frequently find glacial groovings. Note their direction.

There are large areas in the North Central States where the bed rock is deeply buried by the waste rock material which the glaciers brought from the north. Make observations upon the nature of this material, as it is exposed in quarries and cliffs.

FIG. 56.

Road in Salinas Valley, California. The roughness of the road is due to the grinding action of the drifting sand.

Wind Erosion. — We must not overlook the wind in our talk about the agents which are changing the surface of the land, for it is accomplishing more than most of us would believe possible. During one wind storm in southern California it was estimated that two thousand tons of earth were blown from a road about ten miles in length.

In what sort of climate and upon what portions of the earth is the work of the wind most important? What effect has the presence of

a covering of vegetation? Describe the kind of surface which produces dust most easily. Give some common illustrations of the presence of dust in the air. In what portion of the United States are dust storms most severe? Give your reasons.

In our Western deserts, as in the deserts of Africa and Asia, the air is sometimes filled for days with a dense yellow cloud of dust. In the Colorado Desert the prevailing winds blow east-

FIG. 57.

Surface swept bare by the wind. Owen's Valley, California.

ward, and in the course of years they transport vast quantities of fine earth. During severe storms the sand is picked up and carried through the air, and even small pebbles are rolled over and over along the ground. The moving sands grind away the exposed ridges of rock, producing at times curious and fantastic shapes (Figs. 55 and 56). Telegraph poles are cut off by the sand, and the glass of the windows upon the exposed sides of the station houses is etched as though by an artificial blast.

At points where the wind is less strong, sand dunes are formed

and move slowly along to leeward in ranks and files like a great army. Sometimes they are almost mountainous in size, as upon the Colorado Desert (Fig. 229). In Fig. 57 the granitic boulders formed through disintegration and decay would, if it were not for the strong winds blowing away the sand as fast as it formed, be buried in their own waste.

CHAPTER V.

THE COMPOSITION OF THE EARTH.

The Elements. — All living things draw their nourishment in the first place from the lifeless or inorganic matter of the earth, and thus its composition becomes of great importance to us.

Under what three different forms do the materials occur which make up the earth? Illustrate your answer by discussing the forms of water. How is distilled water prepared? What method is used for the artificial production of ice?

Mention a number of mineral substances which are easily changed from one form into another. Find out what you can about the manner in which mercury is prepared from the common ore, cinnabar. At what temperature does mercury become solid?

Place a bit of sulphur in a small glass tube and heat it in the blowpipe flame if possible, although any small, hot flame will do. Note the final disappearance of the sulphur, which volatilizes, and its reappearance in the form of small crystals upon the cold portion of the tube.

Find out what you can about any substances which are fusible with great difficulty or are entirely infusible in any heat to which we can subject them.

As far as the earth has been explored it has been found to consist of more than seventy simple or elementary substances; but of these only about a dozen are sufficiently abundant to interest us here. Two of these elements, oxygen and nitrogen, are abundant as gases and in combination form the air we breathe. Oxygen and hydrogen chemically combined form water, but most of the elements and their combinations form solids.

Pressure as well as temperature aids in determining whether a given substance shall exist in the solid, liquid, or gaseous state. If you will climb a high mountain and attempt to cook upon its

summit, you will find that water boils and turns to vapor at a low temperature because the pressure of the air is slight.

Oxygen is the most abundant and widely distributed of the elements. It is not only an important component of air and water, but also enters into almost all minerals and rocks. The other common elements are silicon, aluminum, calcium, magnesium, potassium, sodium, carbon, hydrogen, sulphur, chlorine, and iron.

Mention, as far as you are able, some use to which each of these substances, or compounds of them, is put in common life.

The elements mentioned form about ninety-nine per cent of the outer portion of the earth, including the rocks, the minerals, the soil, the air, and organic bodies. We know very little about the composition of the earth below a depth of a few miles.

Most of the metals, although we may except iron, must be counted among the rarer elements. Nearly all the metals are heavy and it is not at all improbable, since the specific gravity of the earth as a whole is 5.5, while the surface portion is only 2.65, that the metals are much more abundant toward its center. By the *specific gravity* of any substance is meant its weight when compared with the weight of an equal volume of water.

Determine the specific gravity of a number of common rocks and minerals. The former will give very closely the specific gravity of the outer portion of the earth. For the purpose of the experiment any common balance will answer; the substance should first be weighed in the ordinary manner, and then suspended from an arm of the balance by a thread, so as to be immersed in a dish of water placed underneath. The weight in the air divided by the loss of weight in the water will tell how much heavier it is than water, — that is, will give its specific gravity.

The distribution of minerals in small quantities can be shown in the case of iron. Crush a piece of any dark fire-formed rock, and then with the aid of a magnet remove the particles of iron which may be present. By means of a delicate balance the ratio by weight of the iron to the whole rock can be easily determined.

To what three divisions of the earth do the solids, the liquids, and the gases give rise? In what manner are these substances grouped?

The Difference between Minerals and Rocks. — The solid earth includes the larger portion of the elements, and is composed of *minerals* and *rocks*. The terms *mineral* and *rock* are frequently used in a loose and indefinite sense.

A *mineral* is an inorganic substance having a definite chemical composition and certain distinguishing physical characteristics. A mineral may be composed of a single element, as in the case of sulphur; it may be composed of two elements, as in salt; or of many elements, as in mica. The components of these minerals are always present in the same proportions. Every grain of salt, no matter where it is formed or under what circumstances, has the same percentage of sodium and the same percentage of chlorine. Some of the physical properties of minerals are constant, while others vary. For example, quartz always has the same hardness and always breaks with the same rough surface; but it may or may not occur in distinct and symmetrical crystals, and it may have almost any color. As a usual thing, the physical properties are sufficiently constant to make it possible to distinguish at a glance most of the common minerals.

A *rock*, on the other hand, may have almost any composition. Nearly all rocks consist of a mixture of a number of minerals, and these minerals may be present in any proportion. You might pick out at random a number of minerals and melt them in a furnace, and the resulting mixture when it cooled would be a rock. Nature has done the same, for the common elements, and many of the rarer ones, have been combined without any definite order or proportion in the making of the rocky crust of the earth.

The essential mineral constituents of a piece of common granite are quartz, feldspar, and mica. A rock which contains these minerals will be called granite whether any one of them is present in very small amount or forms as much as half its mass.

Specimens of different kinds of granite should be obtained to illustrate how their appearance varies with the color of the feldspar, and with the different proportions of quartz, feldspar, and mica in each.

Aggregates of a single mineral, which form large masses of the earth's crust, are spoken of as rocks. Marble from this standpoint is a rock, although it consists of an infinite number of grains of the one mineral calcite (calcium carbonate), but, as a rule, rocks are composed of more than one mineral; and while each individual mineral always has the same character, yet the combinations of minerals produce rocks with almost endless variations.

If we should place in a crucible some silicon, aluminum, magnesium, lime, potash, soda, iron, etc., melt them together and then let the heated mass cool very slowly, these various elements would unite as they cool to form the different minerals of a rock. In this connection we must remember that most minerals are not simple elements, but a chemical combination of two or more. Since no two minerals contain the same elements in the same proportion, it can be readily understood that the minerals that would be formed in the above experiment would depend upon how much of each element was put into the crucible in the first place.

Another distinction which we ought to have in mind concerns the use of the terms *mineral* and *metal.* We apply the term metal to a certain class of minerals which consist of a single element, possess a peculiar luster which is called *metallic*, and (with the exception of quicksilver) are malleable, ductile, and good conductors of electricity. Examples of these are gold, silver, copper, lead, and tin. Nearly all the metals are very heavy and all but quicksilver are solids at ordinary temperature.

How Minerals and Rocks are Formed. — We have already learned that heat has had a great deal to do with the making of our earth. All the earliest rocks and many of those of the present day were once molten. After the cooling of the first crust, water played an ever increasing part in the making of rocks. The experiment of volatilizing sulphur and condensing it upon the cold portion of a glass tube illustrates the formation of one class of minerals. In the form of vapor, such minerals rise from

the hot regions below, through fissures in the earth, and are condensed near the surface.

It is difficult for us to produce, artificially, rocks like those in nature, since a long period of slow cooling is required for the formation of most minerals. The glass slag from an assayer's furnace might have made a dense lava-like rock under proper conditions, but the material in the crucible cooled so rapidly that individual minerals could not form and a glass resulted instead.

One method of the formation of minerals can be shown by the saturated solution of some salt, such as sodium hyposulphite (used in the fixing of photographic plates). Allow the solution to evaporate in a flat dish, and the bottom will finally appear covered with crystals. Examine these and note how they resemble each other. Compare them with the crystals obtained in evaporating a solution of common salt.

The Common Rock-forming Minerals. — The rock-forming minerals, which every one ought to be able to recognize, are the various forms of quartz, the feldspars, micas, hornblende, pyroxene, calcite, garnet, tourmaline, talc, serpentine, epidote, and the iron ores.[1]

Quartz is the most abundant of all minerals. Its two constituents, silicon and oxygen, are likewise the most abundant of the elements making up the earth, for they are found not only in quartz, but in many other minerals. Quartz is one of the constituents of many rocks, and also occurs in narrow bands, or *veins*, as they are commonly called, running through the rocks. Sand, made through the crumbling and erosion of rocks, is largely quartz. When the grains of sand become cemented, they form sandstone.

Pure quartz is clear and glassy, but when it contains impurities it exhibits a variety of colors. Pink quartz, smoky quartz, and the purple amethyst are examples. Opal, chalcedony, and agate are varieties of quartz more or less pure and often marked

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[1] It is earnestly recommended that in connection with the study of Chapters V and VI the pupil have at hand a collection of the common minerals and rocks mentioned. These can be obtained from mineral dealers in various parts of the United States.

with rich and delicate tints and bands. Jasper and flint are opaque and exhibit various colors.

Quartz is the hardest of the common minerals. It cannot be scratched with steel and will scratch glass. Its hardness and generally glassy appearance, together with its rough surface when broken, will enable you to recognize it.

There are several varieties of *feldspar*. The characteristic feldspar in granite contains potash as one constituent, and is known as *orthoclase;* while the varieties usually found in the dark rocks contain lime and are known as *labradorite* and *anorthite.* Feldspar may be pink, milky white, or greenish gray, and can be distinguished from quartz — in a piece of granite, for example — by the fact that the grains break with smooth, shining faces, and can be scratched with a knife. When a rock containing feldspar crumbles, the latter softens and turns to *kaolin,* or *clay* as it is commonly called, while the quartz grains fall out, but are otherwise unchanged.

Mica is another of the common minerals and is most frequently found in granite rocks. It is distinguished from all other minerals by the ease with which it splits in very thin, elastic scales. With the aid of a knife blade the mica in granite can be very easily detected. The dark and more common variety, with a luster almost metallic in its character, is *biotite.* The light-colored variety of mica, with a pearly luster, is *muscovite.* The latter occurs sometimes in large tabular crystals, the thin scales of which are widely used for stove windows.

Hornblende is found in many rocks, including granite. It is found usually in long, slender crystals, nearly black in color. This mineral breaks with smooth faces, and is not quite as hard as feldspar.

The mineral *pyroxene* is likely to be found in dark rocks which have no quartz in them. The crystals have a dark brownish or greenish color, and are not usually as slender as those of hornblende. If grains or crystals of sufficient size can be obtained,

the pyroxene will be seen to break along planes which form right angles with each other, while those of hornblende make an angle of about one hundred and twenty-four degrees.

Calcite is a mineral which in abundance stands next to quartz. In the form of marble it often appears as rock masses of great extent. Calcite can be easily distinguished because of its effervescence with acids, and the ease with which it can be scratched with a knife. It cleaves or breaks into obliquely angled forms, with smooth faces. The crystals are sometimes as clear as glass and are then known as *iceland spar*.

Dolomite is a mixture of calcium carbonate (calcite) and magnesium carbonate. It forms one variety of limestone and marble, but is not as abundant as ordinary marble. It is a little harder than calcite and does not effervesce as readily.

Garnet is quite a common mineral in crystalline rocks, and forms the little reddish grains in the sands of many streams. It occurs in roundish crystals, usually bounded by twelve plane faces, and cannot be confused with any other mineral which you are likely to meet. Garnets of a reddish color are most common, although many other tints are known. When scattered through a rock mass, the crystals are as a rule very small, appearing like mere grains. This mineral is a little harder than quartz. Precious garnets are clear and of value as gems.

Tourmaline is not abundant, although found in many rocks. It usually presents the form of long and very slender crystals of a black color, grouped in radial clusters. The green and pink varieties of tourmaline possess great value as gems.

Talc is one of the softest of all the minerals and is distinguished by its soapy or greasy feeling.

Serpentine is a very abundant mineral, and in many parts of the United States it forms extensive rock masses. Serpentine is the product of the alteration of several minerals, chiefly olivine, in rocks having an igneous origin. It has a dark greenish color and is nearly as soft as talc.

Epidote is present in rocks as yellowish green grains and streaks. Occasionally the mineral forms slender, finely-shaped crystals. Epidote is found usually in rocks that are somewhat decomposed.

Such ores of iron as *magnetite* and *pyrite* are very generally scattered through rocks. The first of these is particularly abundant. Dark, heavy rocks contain much magnetite, as you can show by crushing a small piece of such a rock and moving a magnet through the powder. Magnetite is an oxide of iron and is black in color. By an *oxide of iron* is meant a combination of iron and oxygen.

Pyrite, which is a sulphide of iron (a combination of iron and sulphur), has a yellowish color and metallic luster, and is almost as hard as quartz. Heated over a hot flame, it gives the odor of sulphur. Copper pyrites is usually found in veins associated with iron pyrite, but is distinguished by being softer and of a deeper yellow.

In order to recognize the common rock-forming minerals, particularly those in coarse-grained rocks, you will need nothing more than a piece of sharp-pointed steel — a knife blade will answer — for determining hardness, and a little weak hydrochloric acid to test for carbonates. The luster (meaning the kind of light reflected from the surface), color, hardness, crystal form, and the nature of the surface formed by breaking are the important physical properties which must be considered in determining a mineral.

Non-metallic Minerals of Especial Economic Value. — *Gypsum* occurs both as veins cutting through rocks and as layers between other rock layers. Gypsum is, next to talc, the softest mineral and may be easily scratched with a finger nail. It is reddish gray or white in color. The white, fine-grained variety is *alabaster*. For what is this variety used? Gypsum when burned forms plaster of Paris, in which form it is used for many purposes. Mention some of them.

Calcite, already described, is, when clear and free from flaws, of great value in optical instruments. Describe some of the uses of marble and limestone. How is quicklime prepared (Fig. 58)?

Rock salt is so named because it occurs in solid rock-like masses. It is found in extensive beds, either upon the surface of the desert basins of the West or in strata far below the surface.

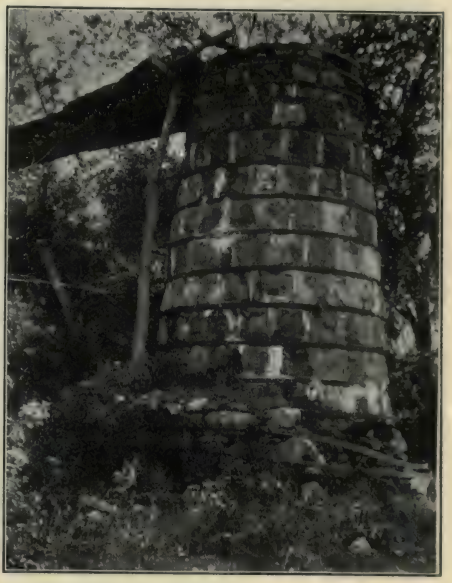

FIG. 58.

A lime kiln. Note the staging for dumping in the lime at the top and the opening for taking it out at the bottom, after burning.

Salt, soda, borax, and the nitrates of potash and soda are obtained from deposits upon the bottoms of dried-up lakes or lagoons. These mineral substances were originally distributed through the rocks as constituents of the minerals composing them, but during the processes of rock decay already described they were dissolved by percolating water and carried away. Rivers usually reach the ocean, but in many desert regions, notably in the southwestern portion of the United States, there exist depressions in the land from which the water never had an opportunity to flow away to the ocean. Some of these depressions were once occupied by lakes. As the climate became drier, the water of many of the lakes disappeared by evaporation and the minerals which the streams had brought in solution were left mixed with the mud over their bottoms.

Under the influence of the desert air, the surface dried out. Capillary attraction drew the moisture remaining below upward to the dry surface and with the moisture came, little by little, the salts which were mixed with the mud, until a soft white

Fig. 59.

The white surface of the southern arm of Death Valley, California.

layer or crust covered the ground (Fig. 59). This process is known as *efflorescence.*

Leave a piece of butter exposed to the cool, dry air and note what happens to the salt distributed through it. Take a dry brick, place it for some minutes in a weak solution of soda and then leave it exposed to dry air; describe the result.

We are all familiar with coal and petroleum and know something of the manner in which they were formed. While both are of organic origin, — that is, they were formed from the bodies of

once living things, — the conditions under which they came into existence were not at all alike.

Coal came from the accumulation, in swampy places, of the stems and leaves of a luxuriant land vegetation. With a changing of the level of the land, it frequently happened that these

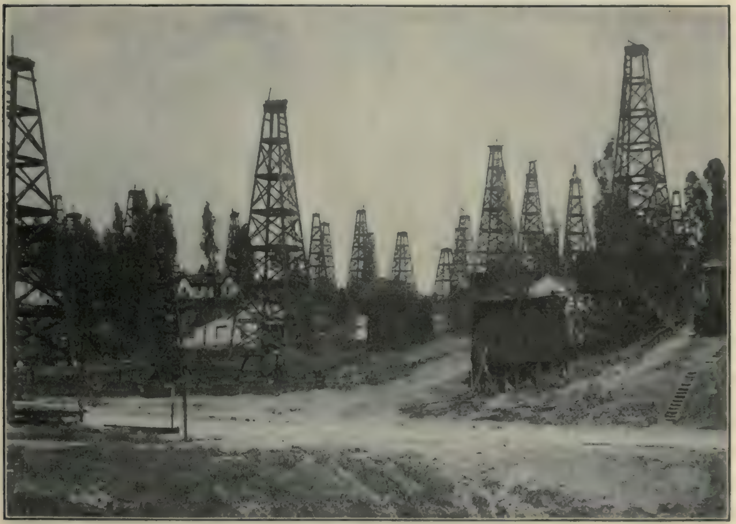

FIG. 60.

Oil wells in Los Angeles, California.

swamps, with their thick deposits of decaying vegetation, were buried to a great depth under deposits of sand and clay. The plant remains were there subjected to great pressure and slowly changed to coal. With an uplift of the land running water began to wear away the surface and at last exposed many of the beds of coal.

Petroleum is derived from ocean life. This was chiefly fish and low forms of microscopic organisms, including both plants and animals. At death their skeletons, consisting of either lime or silica, together with some organic matter, slowly formed accumu-

lations upon the bottom of the ocean. After the lapse of ages, as the sediments were squeezed together and changed by heat, the organic portion began to be driven off in the form of gas and oil.

Fig. 61.

A spring flowing thick oil (tar) and water. Coast Ranges of California.

A freshly broken piece of limestone or shale from an oil field will generally give out a fetid or petroleum odor. A bottle of crude petroleum should be at hand for examination and comparison with the refined product.

Find out what you can about the origin of *asphaltum* and *bituminous rock* and their uses. What are the by-products formed in the refining of petroleum? Find out what you can about the method of obtaining petroleum (Fig. 60). What is the cause of springs of petroleum (Fig. 61)? Do they flow for the same cause as springs of water or are there other agents concerned?

Graphite, often called *plumbago* or *black lead*, is another mineral of organic origin. It is found in the older rocks and is believed to represent coal which has been changed by great heat and pressure far below the surface. Graphite, although pure carbon, is not affected by heat. Describe the properties and uses of graphite.

Diamond is the hardest and most valuable mineral, being formed of pure crystallized carbon. Its origin is not known with certainty in all cases; but in South Africa, at least, it was formed in the hollows of a mass of lava lying in the throat of an old volcano. Long ago hot vapors containing carbon penetrated the lava and the carbon was deposited as little crystals. Diamonds of a very small size have been formed artificially in furnaces where there were heated vapors containing carbon.

Asbestos is a fibrous mineral which it is not easy to confuse with any other. It has many uses in the chemical laboratory and other places where a fireproof material is needed. Mention some of these uses.

Sulphur is a mineral easily volatilized.

Why does sulphur occur so frequently about the orifices of sulphurous springs and volcanoes? From what part of the world is most of our sulphur obtained? Describe the appearance and properties of sulphur.

Sulphur is also derived from iron pyrite by heating it in a furnace. The sulphur is driven off in the form of a vapor and is conducted to cool chambers, where it is condensed.

Some of the Metallic Minerals. — In taking up this section, you should recall the difference between minerals and metals (p. 76). The metals include most of those minerals which consist of one element.

Gold, platinum, silver, iron, and copper occur native in the earth. By *native* we mean in the pure metallic state.

Gold may occur in combination with other substances, forming minerals which do not look like gold itself.

Platinum is always found nearly pure. It is much rarer than gold and has important uses in the laboratory.

Mention some of the uses. Where does the most of our platinum come from?

Native iron is very rare. The most that is known has come to the earth in the form of meteorites (Fig. 62).

What is the size of some of the largest meteorites known?

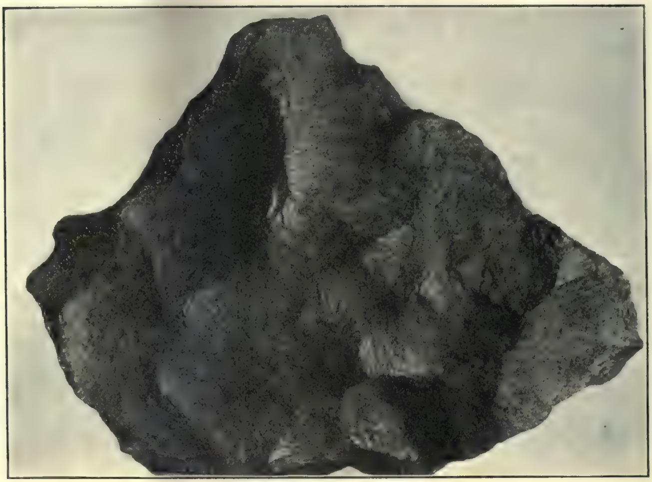

FIG. 62.

A fragment of the Canyon Diablo, Arizona, meteorite. This meteorite contains microscopic diamonds.

The important ores of iron are the oxides; one of these is known as *hematite*, another as *magnetite*, and a third as *limonite*. From these ores the iron is obtained by smelting in a furnace. If you cannot visit a furnace where ores are being treated, look up some description of the process.

Silver occurs more often in combination with other elements than it does native. The ores have to be treated to a complicated process to extract the metal.

Copper is found native chiefly in the Lake Superior region. In most mining districts it occurs in combination with sulphur and other elements. The most common ore is *chalcopyrite*, or *copper pyrite*. Specimens of native copper and chalcopyrite should be compared so as to get a clear conception of the difference between a metal and a mineral.

Lead, zinc, tin, antimony, nickel, and *aluminum* can only be obtained in the form in which we know them through treating the original ores to various complicated processes. Aluminum, although it is one of the most abundant elements of common rocks, is so strongly bound to other elements that only recently have processes been discovered to obtain it cheaply.

What are some of the properties of aluminum? Find out what you can about the uses and properties of lead, zinc, tin, and nickel.

Ore Deposits and how They are Formed. — Traces of most of the rarer elements, as for example gold, are found in the common rocks and in sea water. If this were the only form in which the metals existed they would be of very little use to us. It would be impossible to obtain them in any quantity. Nature has, however, during the long period in which the surface of our earth has been worked over, concentrated many valuable minerals in such forms that we can use them.

We employ the term *ore* to designate the metals and their compounds as they exist in the veins or rocks where they have been concentrated. The various salts which have already been mentioned as occurring in the basins of dried-up lakes were concentrated as a result of rock decay or weathering; but this would not have given us the metals and ores, for they are distributed through the rocks in too minute quantities and besides are not readily soluble.

The concentration of the mineral particles into workable deposits was made possible, in the first place, because of movements of the earth's crust, which fractured the rocks and gave freer access of the surface waters to the heated interior.

In what portions of the earth would you expect to find the most abundant mineral deposits?

Far within the earth chemical action is going on, and the entrance of water through the fissures makes this all the more active. Fissures have a further importance from the fact that

FIG. 63.

Narrow veins of white gold-bearing quartz, cutting across black slate in which there is a gray-colored dike of igneous rock. Mother Lode, California.

by means of them the effects of the chemical process far within the earth can reach upward into the cool surface rocks.

We have already learned that rain water contains carbonic acid gas. This water, in percolating downward into the earth, dissolves some of the alkalies, such as soda and potash. It is now in such a condition that, when it has gotten far down in the earth, where the pressure is great and the temperature very high, it can dissolve other minerals. This is nature's great laboratory, and

many things go on there of which we can gain no knowledge except that furnished by mineral springs and volcanic eruptions.

The water does not remain in the depths of the earth. It was drawn down by gravity and capillary action, but steam and other gases exist there and they drive it back again toward the surface. As the water continues its circulation through the fissures of the rocks, it becomes highly impregnated with many minerals. It creeps slowly through the small fissures, but where they are large, it may be almost the volume of a river. In the bottom of the Comstock mines of Nevada, such quantities of hot water were encountered that mining had finally to be abandoned, because the water could not be pumped out as fast as it came in.

FIG. 64.

An outcrop of one of the great quartz veins of the Mother Lode, Coulterville, California.

The upward moving currents when they reach cooler rocks begin to deposit a portion of their load. In places the veins of mineral matter so deposited are very narrow (Fig. 63); but where the fissures are enlarged by the action of the water, the deposits may attain a thickness of many feet (Fig. 64).

Dissolve all the salt that you can in hot water and then let it stand and cool, noting the result. What is meant by a saturated solution? Will a solution saturated at a low temperature still be saturated if the temperature is raised?

In gold-bearing regions the veins consist largely of quartz, through which are scattered particles of gold, iron pyrite, chalco-

pyrite, and other minerals. These veins with their contents were probably deposited from hot alkaline water; for many minerals, including quartz, are soluble in such water. The conditions leading to the formation of veins carrying silver and lead were somewhat different, for there is little quartz, but in its stead much calcite.

Veins vary much in shape, for some are bunchy and have no great extent, while others form fairly regular sheets, and have been followed in the workings of mines for several thousand feet.

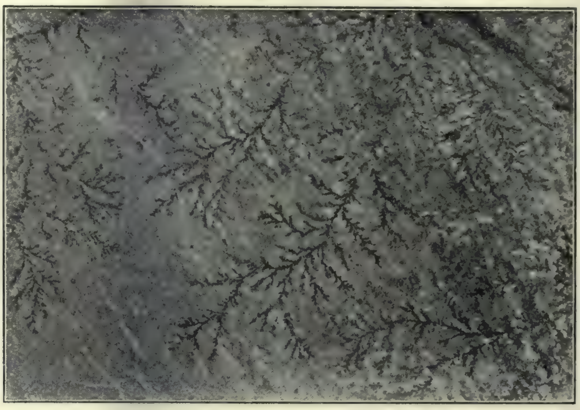

FIG. 65.

Fern-like deposits of manganese, formed by water percolating between layers of slate.

The deepest gold mines have penetrated more than half a mile into the earth, while the copper mines upon the shores of Lake Superior are about one mile deep.

Let us call to mind now the experiment with sulphur (p. 73). Heated vapors as well as water ascend through many of the fissures in the earth, and these vapors frequently carry such minerals as sulphur and quicksilver and deposit them in the cooler rocks near the surface. This process, by which substances are changed into vapor by heat and then condensed as solid particles again, is known as *sublimation.*

There have been in quite recent times volcanic eruptions in the Coast Ranges of California, and in some of the quicksilver mines which abound there the deposition of ores from both vapors and hot mineral-bearing waters is now taking place. Among the minerals so deposited are silica, lime, quicksilver, gold, and sulphur.

Which of these minerals are most likely to be deposited from vapors?

Fig. 66.

Quartz veins. Note the bunchy vein at the left.

Does the water of most springs and wells come from very deep in the earth? From what kind of rock does the water in the wells in your neighborhood issue? Would a person be likely to obtain water from a well sunk in granite? Under what conditions might granite furnish water sufficient for a well? Illustrate by a sketch. Note the nature of the orifice of any spring which you can visit. Why is it that water is so abundant in most mines? What conditions determine the location of the veins which miners are seeking? Distinguish in Fig. 66 the veins

and bunches of quartz and their position with reference to the layers of the rock. What does the presence of polished or "slickensided" surfaces on the walls of a vein mean (Fig. 17)? Search the rocks in your neighborhood for veins of any kind. Are you more likely to find veins in old or recent rocks? Give your reasons.

The lead and zinc ores of the Mississippi Valley occur at points where the rocks have been broken and fissured, but appear

FIG. 67.

Hydraulic mining in the Klamath Mountains, California.

to have been formed by surface waters moving downward, rather than by water coming directly up from the heated interior. The limestone rocks abundant in this region, together with the mineral particles scattered through them, are slowly dissolved by the rain water as it percolates downward. Far below the surface the minerals are concentrated in vein-like bodies in the fissures and crevices.

Such minerals as gold, platinum, and tin are frequently found in the gravels of streams or in the sand of the ocean beach. In these places the land has been subjected to erosion for ages. The disintegrated rock is mostly carried away, but the heavy minerals remain and thus become concentrated so as to be of commercial value. In regions of mineral veins such deposits in the stream beds are often exceedingly rich.

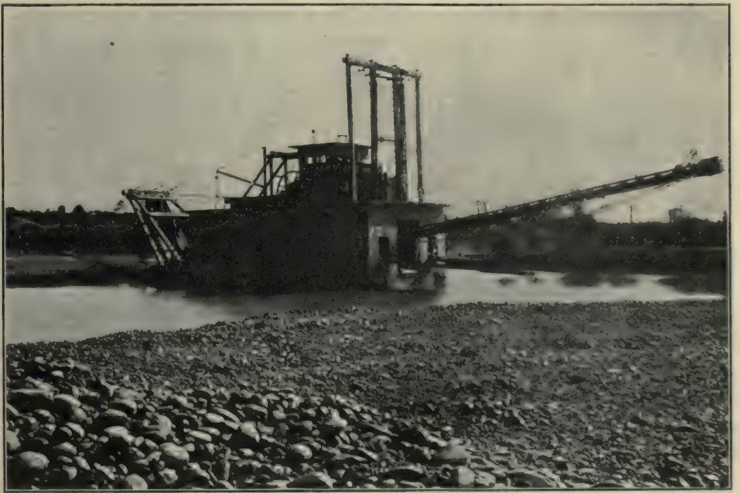

FIG. 68.

Dredging for gold in the bed of Feather River, Oroville, California.

Find out what you can about *placer* mining and *hydraulic* mining (Fig. 67).

The gold in the old river beds of California was collected through a period of perhaps hundreds of thousands of years, as the result of the decay and erosion of several thousand feet in thickness of rocks containing quartz veins.

Employing a shallow dish and the miner's method of "panning," wash out some gravel taken from the bed of any convenient creek. The material that remains last in the pan will contain such heavy minerals as garnet, magnetite, and particles of gold, if there are any present.

Accessibility of Mineral Deposits. — Some mineral deposits are very old, others are being formed now. Every part of the earth's surface has probably at one time or another exhibited mineral deposits, but at present there are broad valleys and even mountains in which none of importance are to be found. What is the reason for such a condition?

During the changes of level of the land at different times in the past, large areas containing mineral veins have sunken beneath the ocean and have been covered with sediment from the land until buried beneath a layer thousands of feet in thickness. Such a region again raised from the ocean would have no visible mineral deposits. In the course of time, however, they might be brought to light in the canyons cut by the streams. In the bottom of the canyon of the Colorado are mineral veins of which we never should have known anything if it were not for the mile-deep trench worn by the river.

The great lava flood of the northwestern United States has buried many thousand square miles of supposed mineral-bearing rocks, leaving only the higher mountains uncovered. There are few ores in the recent lavas, but in the ages to come erosion may remove the lavas and expose the old surface again.

Thus it appears that many events are concerned in the making and preservation of ores in such a position that we can get at them.

Make a cross section sketch of an old land surface covered by newer rocks, and show how the earlier land may become exposed.

Sketch a section of horizontal rocks illustrating the undisturbed strata of the Mississippi Valley, and include in them a layer of coal two thousand to three thousand feet below the surface. What difficulties lie in the way of getting at this coal? Would its presence be likely to be suspected?

To the above sketch add another showing the rock layers folded as in the Appalachian and Rocky Mountain regions, and then illustrate how the decay of the rocks and the work of the streams would expose the deeply buried seams of coal so that miners could discover them and mine them easily.

CHAPTER VI.

THE COMPOSITION OF THE EARTH. — Continued.

The Story of the Rocks. — It is thought that the first rocks were all formed by heat. What are such rocks called? As soon as these rocks were exposed to weathering influences, they began to crumble, and shortly a layer of waste accumulated over the surface. This waste we call *mantle rock*, because it forms a sort of covering over the solid rocks (see p. 113).

The flowing streams loaded themselves with rock waste from the steeper slopes and carried it as fast as possible to the lakes or oceans, where, after being spread far and wide by the currents, it settled to the bottom.

Living things filled the waters, and when they died their bodies also aided in building up deposits upon the bottom until a thickness of thousands of feet had accumulated. Little by little the layers of sediment became pressed together as a result of their own weight, and in places they were folded deep in the earth and greatly changed. Wherever these sediments, or rocks as we should perhaps call them, were raised above the level of the water, they began to decay and crumble again. And thus the ceaseless round of change goes on. It is going on now as it has been going on in the past. This is in brief the story of the rocks.

Describe the life history of a piece of lava, that is, its origin, present character, and final decay. Are any rocks free from the attack of destructive forces? What common constituent of rocks appears never to be affected by the atmosphere? Describe the origin of the particles of sand in a piece of sandstone, and tell what you think may have been their history from the time they were first formed in some igneous rock until united in the sandstone. What do you think about

the number of varieties of rocks now to be found as compared with those existing in the early history of the earth? Give reasons for your conclusions. What are the agents which sort the waste of the crumbling rocks?

Make a collection of all the different rocks in your neighborhood, those in solid ledges, as well as pebbles from the streams or beach. Each specimen should be in as fresh a condition as possible and present at least one new surface of fracture. Most of the rocks showing

FIG. 69.

A porphyry: an ancient volcanic rock.

little crystal-like grains, as well as the dark, fine-grained rocks, are of igneous origin.

Igneous or Fire-formed Rocks. — In our talk about igneous rocks, it will be convenient to divide them into two broad classes. Those, like lava, which cooled on the surface or in fissures near it are generally fine-grained, or have distinct crystals scattered through them as though sprinkled in (Fig. 69). The rocks formed deep within the earth, of which granite is the most

common example, have a sort of granular appearance, because all the component minerals are of about equal size.

Lava is the general name for volcanic rock.

What is there about the appearance of lava which would lead you to believe it had ever been molten? Explain the little roundish pores which are scattered through most lava specimens.

FIG. 70.

A jagged piece of scoria.

If the pores are very numerous, the rock is called *scoria* (Fig. 70). Lava in which the pores occupy the greater part of its bulk, so that it appears almost like a piece of hardened froth, is called *pumice*.

Obtain a piece of pumice (drug stores usually keep it) and make a note of its characteristics. Of what economic value is pumice?

When pumiceous lava is blown violently out of the throat of a volcano, it is broken into fine dust-like particles, which rise high

in the air and are distributed widely over the country by the winds. Lava in this state is known as *volcanic ashes.*

Powder a piece of your pumice and you will have what is practically volcanic ashes. Place a piece of pumice upon water and explain what takes place.

FIG. 71.

A recent flow of obsidian lava. Mono Craters, Eastern California. Contrast the rough barren surface with that upon which trees are growing.

Following the eruption of Krakatoa in the East Indies in 1893, the sea for many miles around was dotted with fragments of pumice.

Lava that has cooled so quickly that the elements of which it is composed could not unite (crystallize) in distinct minerals forms *volcanic glass* or *obsidian* (Fig. 71). If this lava had cooled slowly, it would have contained several such minerals as quartz, feldspar, hornblende, pyroxene, and mica.

p. 99

FIG. 72.

Columnar lava. Devil's Post Pile, Sierra Nevada Mountains.

For what purposes is obsidian used by savages? A visit to an assay office will give you an opportunity to observe the glassy slag formed in the crucibles and the manner in which it breaks up on rapid cooling.

The columnar structure observed in many lavas is the result of contraction in the molten masses as they cooled. The columns are four to six sided and generally stand at right angles to the surface of the lava (Fig. 72).

FIG. 73.

A dried-out mud flat.

If you can find a bed of drying mud, observe the cracks which are forming and note if there is any resemblance between the blocks and the columns of lava. Explain why the mud cracks as it does (Fig. 73).

We distinguish different kinds of lavas according to the minerals which they contain. You will generally be right in calling a very dark lava *basalt*. You can often see the crystals of feldspar and pyroxene scattered through the rock. Basalt is heavier than most rocks, for it contains a good deal of iron.

If you find a light-colored lava in which crystals of quartz, feldspar, hornblende, or mica appear, the rock is probably *rhyolite.* The rock may have a glassy appearance, with some of these crystals scattered through it.

There is another group of rocks, intermediate in color between basalt and rhyolite, known as *andesite.* This rock usually contains no quartz, but you will be likely to see slender crytals of hornblende or short crystals of pyroxene, in addition to those of feldspar.

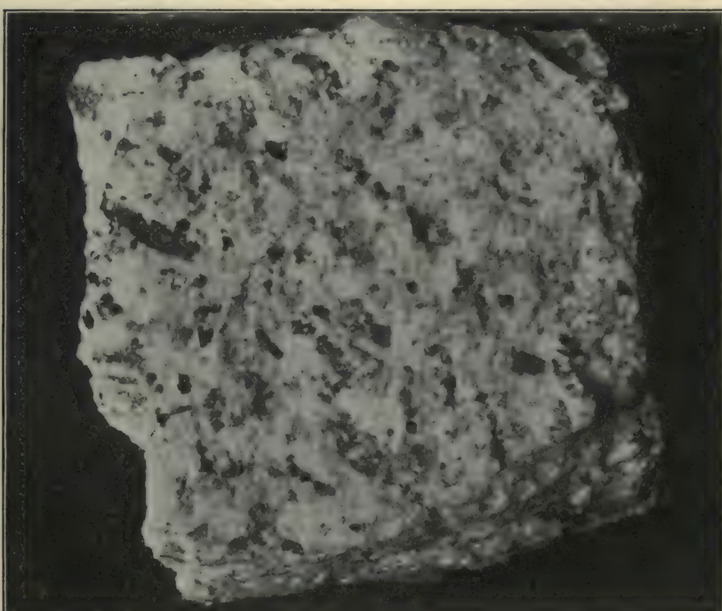

Fig. 74.

Granite.

Wherever the land is the highest and the slopes the steepest, there the rocks are crumbling and wearing away most rapidly. Consequently it is along mountain axes, where the earth's crust

has been pushed high in the air, that we find rocks exposed which were once more deeply buried than any others that we know.

Granitic rocks are the most common of those formed far beneath the surface (Fig. 74). They now appear over hundreds of thousands of square miles because of the wearing away of the overlying rocks which once hid them from sight. Granite

FIG. 75.

A dike of granite cutting through schist.

is familiar to us all, and its three characteristic minerals — quartz, feldspar, and mica — are easily recognized. In some granites hornblende partly or wholly replaces the mica. If the rock contains no quartz, it is called *syenite;* and if the orthoclase feldspar (potash feldspar) is replaced by another variety of feldspar containing soda, the rock is then termed *diorite.* Dark, heavy rocks containing labradorite feldspar and pyroxene, and

usually possessing a coarse-grained texture, are known as *gabbro.*

A granitic rock is often called *gneiss* (Fig. 76) if the constituents, particularly the mica scales, are arranged in a parallel manner so as to give the rock a banded appearance and make it split more easily in one direction.

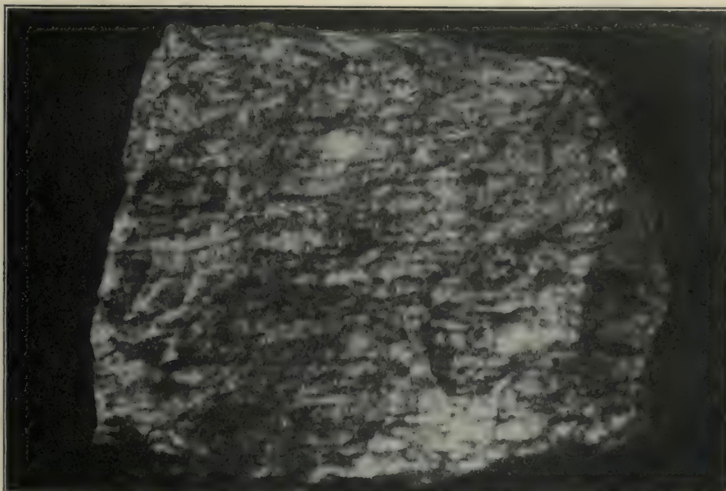

Fig. 76.
Gneiss.

Rhyolite has the mineral composition of granite, and we may consider it granite which has cooled upon the surface and thus taken on a different appearance. In a similar way the lava andesite corresponds to diorite, and the lava basalt to gabbro. There are innumerable varieties of igneous rocks, but those mentioned are the ones most commonly met with and these should be known by all.

Sedimentary Rocks. — We give the name *sediment* to the material which collects in the bottom of a glass of muddy water.

Examine the bottom of a dried-up pond and see if there is not a similar deposit. What would lead you to suppose that materials are collecting upon the bottom of all bodies of water? Does this accumulation of sediment go on more rapidly in quiet or in moving water? Examine the bottom of shallow lakes and the marginal sea bottom when the tide is out. What do you find the bottom composed of? Is it at all like the surface of the land? What is the difference in the nature of the accumulation upon the bottom in quiet water and where there is a moderate current? Is the water quiet or in rapid movement where

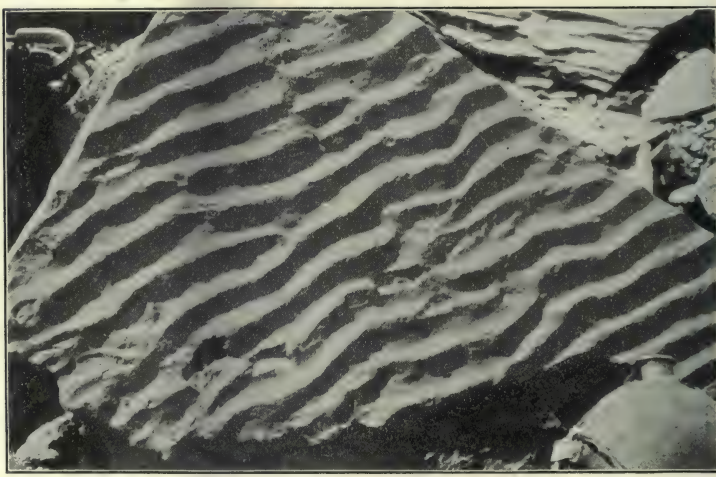

FIG. 77.

Ripple-marked sandstone from the crater of Coon Butte, Arizona.

beds of pebbles are formed? Seek for ripple-marked sands near the shore of some quiet body of water. The ripple-marked sandstone (Fig. 77), formed long ago, must have been sand once in the bottom of some shallow water where there were waves and currents just like those of to-day.

The water in the same place is quiet at some times, at other times it is in rapid motion, and so we should expect what we actually find to be the case, namely, that the sediments are arranged in layers, some fine and others coarse. Because of this

fact the sedimentary rocks are also known as *stratified* rocks; that is, they are built up of strata piled one above another (Fig. 78). Igneous rocks are not stratified, a fact which is important in distinguishing between them and sedimentary rocks.

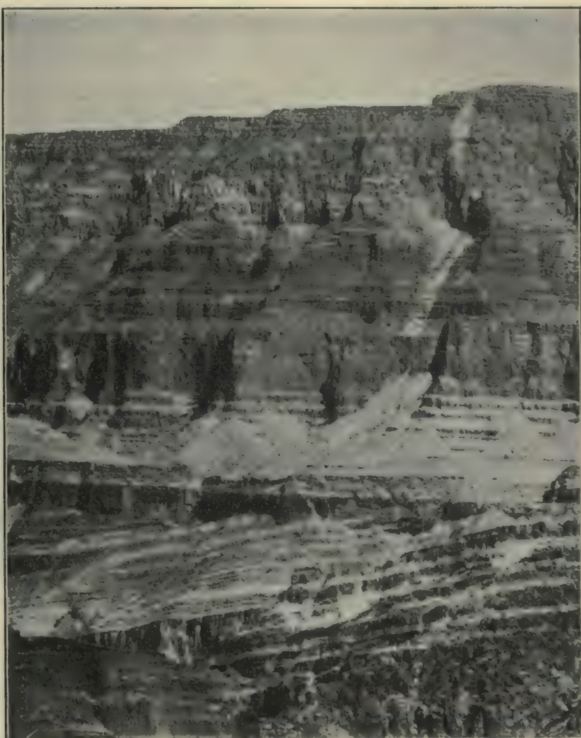

FIG. 78.

A cliff in the Grand Canyon of the Colorado.

Where do the materials come from which discolor the water of the lake or ocean? At what season are the streams most loaded with waste rock? When do the waves accomplish the most?

Using two glasses of muddy water, place a little salt in one. Observe in which the sediment settles first. What effect would you expect the

salt of the ocean water to have upon the silt in suspension. What is the meaning of *flocculation?*

Give a detailed explanation of the conditions which lead to the formation of beds of pebbles in one place, sand in another, and clay in another. Are there any sediments accumulating upon the ocean floor beyond the

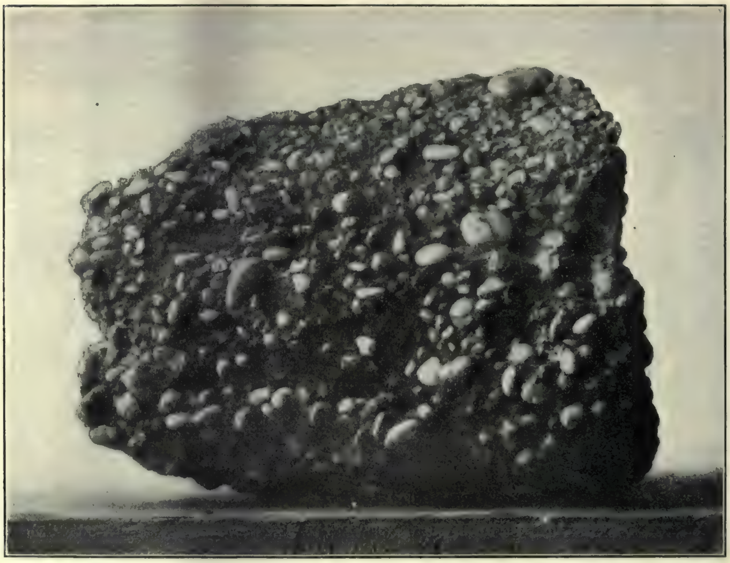

FIG. 79.

Conglomerate.

reach of currents from the land? Dredging in deep water shows a soft substance upon the bottom, called *ooze* (p. 433).

Examine carefully the bed of some stream for the purpose of determining at what points in its windings bars are formed. Where is the finest material dropped? If you can find beds of clay, sand, and pebbles exposed in some cliff, describe the nature of the water currents which formed each.

We cannot go deep in the earth where the process of changing the soft sediments to stone is going on, but we can learn something about it by studying a gravel cliff. In many places you

will find the pebbles and grains of sand partly cemented by some substance which fills the spaces between them. Drop a little acid upon this and you can easily tell what it is. What is the source of this cementing material?

A bed of pebbles thoroughly cemented forms the rock known as *conglomerate* (Fig. 79). When a bed of sand has been subjected to pressure and the little spaces between the grains have been filled with some cementing mineral once in solution in the water which percolated through it, *sandstone* is formed. If the pressure has been very great, the grains will be firmly attached to each other without any cementing material. Many sandstones quickly fall apart when exposed to the air. Can you tell what is the cause of this? When a bed of clay has been subjected to very great pressure, it is turned into a rock known as *shale*, which breaks in thin, irregular pieces.

What changes will take place in a piece of shale on long exposure to the weathering agents?

Have the rocks just mentioned any commercial value? What are your reasons for believing the statement that beds of shale, sandstone, and conglomerate were formed beneath some body of water? What bearing upon this question has the presence of the remains of animals which once lived in the water? Could you say whether the beds were formed in fresh or salt water?

In nearly all parts of the country where the sedimentary rocks are exposed, you will find, if you look carefully, fossil shells and corals which have lain buried for millions of years. Compare any that you may find with specimens of recent sea shells and corals. The less the resemblance between them, the older are the rocks from which the fossils came.

If you have the opportunity, study carefully the portion of the sea bottom which is exposed when the tide is out and satisfy yourself as to the accumulation of dead shells. Make excavations in the mud and sand and see if you do not find them buried in great numbers.

Organic Rocks.— The sedimentary rocks which have just been described are formed mechanically. They have had little, if anything, to do with life. But there is another class of rocks, also

formed under water, which consists essentially of the skeletons and bodies of organisms.

Infinite numbers of the living things in the ocean have no hard skeletons, and when they die their bodies are dissolved in the water. There are others, however, that have a hard framework, and when these die, the fragments of this framework, or

Fig. 80.

A rock formed of sand and sea shells.

skeleton, collect upon the bottom, and in the course of time form beds many feet in thickness (Fig. 359).

The skeletons of sea organisms are of two kinds. One kind is calcareous, that is, formed of lime; while the other is silicious, that is, formed of silica, the substance of quartz.

The *corals* are perhaps the most important rock builders.

They are abundant in the shallow waters of tropical oceans, where they form extensive beds of limestone.

Find out what you can about *coral* islands and *barrier* reefs. Do corals live in deep water or near the surface? Beds of limestone containing corals are abundant in many portions of the United States. What would this lead you to conclude was at one time the condition of the places where they are found?

Besides corals, there are *molluscs* whose shells often form rock masses (Fig. 80), and the small, almost microscopic, organisms known as *foraminifera*, whose skeletons can be detected thickly matted together in many limestone beds.

Other microscopic organisms, such as *diatoms* and *radiolaria*, have silicious skeletons, and their remains have given rise to flint and jasper rocks.

Diatoms abound also in fresh-water lakes and have produced deposits which are less changed than the most of those formed in the ocean. The beds consist of a white, powdery material, known as *diatomaceous earth*, which has an important use as a polishing agent.

Give an explanation of the origin of the lime and silica which the sea organisms build into their skeletons.

Coal is more like a rock than a mineral, for it does not have a uniform composition. Beds of coal form a not insignificant portion of the stratified rocks in many places. The vegetation which has produced coal could not have accumulated in any quantity upon the dry land, for land vegetation as it decays in the air is completely oxidized, and the particles are finally scattered by the wind. The vegetation now accumulating in swamps aids us in understanding the beginnings of a coal bed.

Investigate the black earth of some swamp and show as nearly as you can, by washing, the proportion of vegetable matter which it contains.

We can trace this vegetation which has been deeply buried and then exposed again by erosion, through all stages, beginning with the *peat* in the swamps of the present day, to brown coal

or lignite, bituminous coal, and anthracite or stone coal. The last stage in the process of change is represented by graphite.

Which coal is likely to be the better, that which has been formed recently, or that which is older? Give reasons for your conclusion.

Metamorphic Rocks. — The term *metamorphic rock* is usually given to a sedimentary one which, during movements of the crust,

FIG. 81.

A Mexican making adobe bricks.

has been so deeply buried and so changed by heat and pressure that it appears to be an entirely different rock. Indeed, it may be melted and squeezed into fissures in the rocks above, becoming then an igneous rock.

Clay shale through heat and pressure is turned into *slate*, that dark rock with which we are all familiar. Mention some of the uses of slate. A still greater change produces *mica schist*. Like slate, this splits easily, but not in as thin, regular layers. The

rock is no longer clay, but a mass of shining mica scales and grains of quartz. The material of the shale or slate has *crystallized* into new minerals.

Sandstone is changed by the same process into the rock known as *quartzite*. This rock is almost pure quartz, being very hard and durable. Quartzite, like the quartz formed in veins, may have almost any color, but can usually be distinguished by being more granular than vein quartz.

Heat and pressure deep within the earth turn beds of dull earthy limestone into clear sparkling marble. The particles of the limestone have become crystallized in the marble, and are now a mass of calcite granules which break with smooth, shining faces.

You should procure, if possible, specimens of clay, shale, slate, and mica schist, to illustrate the different stages in the transformation of sediment. It will be instructive also to compare sand, sandstone, and quartzite, as well as limestone and marble.

Describe some of the uses of clay. Find out what you can about adobe buildings (Fig. 81). Describe the process of brickmaking. Why do the bricks turn red when they are baked?

If no rocks outcrop in your neighborhood, you will find a large variety among the pebbles in almost any creek bed. Can you tell why this is? Seek for all the different kinds of rock used in buildings near your home, and find out where they came from. What building stones are most resistant to decay?

The Age of the Different Rocks. — From the time of the formation of the most ancient rocks of the globe down to the present, the weathering of the surface, the gathering of sediments upon the ocean floor, and the eruption of molten lava have constantly been making over old rocks and building new ones into the crust.

Our study of physiography has mainly to do with the earth as it is to-day, and the transformations which it is undergoing, but we ought to know something of the manner in which the different rock formations are arranged and classified. It cannot be told how old in years the various rocks are, but their relative age

can be learned with considerable exactness. A scale has been constructed, beginning with the oldest groups of rocks and leading down to the present. To each main group a name has been given, a name taken sometimes from the locality where the rocks are well shown, and sometimes from the most characteristic form of life buried in its rocky strata. There is, for example, the Carboniferous period, or the period of coal plants; the Devonian period, or the age of fishes, named from Devon, England, where it was first studied.

Long study of the remains of plants and animals buried in the rocks shows that the oldest were low and simple forms, and that living things have been slowly changing and becoming more highly organized. This fact is used as an aid in classifying the rocks. The very ancient rocks in which we find no life have been given a certain name. Forms of life lower than vertebrates characterize a less ancient group of rocks. A still younger group, in which remains of fish first appear in abundance, has another name.

We are also aided in our study of any particular group of rocks by noting its relation to the adjoining rocks above and below. Strata at the base of a cliff must be older than those at the top. Sometimes a cliff will expose two formations, the strata of the one at the bottom being steeply inclined, while those at the top rest nearly flat upon the planed-off edges of the lower (Fig. 78). Such a cliff tells an interesting story of happenings long ago. After the strata at the bottom were deposited as sediments in some ancient ocean, movements of the earth's crust took place, the portion of the ocean bed occupied by them was elevated, and the strata tilted and folded. Then they were exposed to weathering and erosion, and after a long time they were worn down to the surface shown in the cliff. Some time afterward the land sank beneath the water, and a new series of sediments, represented by the level strata at the top of the cliff, was deposited. These sediments were in turn hardened into rock, and uplifted,

and finally exposed to our observation through the work of running water.

In nearly all parts of the country a greater or less number of the rocks which we have been studying are exposed. You should not be satisfied with an examination of specimens in the laboratory, for you will learn much less from them than if you see them in their natural position out of doors. Try to distinguish between the rocks of sedimentary and

FIG. 82.

Layer of dark soil at top, broken rock beneath it and solid bed rock at the bottom. Coast of California.

of igneous origin. Look for *veins* formed by deposition from water, and for *dikes* of material once molten, which in many places intersect the sedimentary rocks.

Mantle Rock. — The rocks which we have been studying might be grouped together and termed *bed rock,* to distinguish them from the covering of rock and soil which in the course of time gathers upon them. This superficial layer, which hides the bed rock over large areas, is known as *mantle rock.* We have

already learned something of the manner in which it is formed through the decay and crumbling of the bed rock.

Review briefly the forces concerned in the breaking down of the rocks and the removal of the waste materials.

We must distinguish two kinds of mantle rock, just as we do two kinds of soil. There is, first, that which accumulates directly over the decaying rocks (Fig. 82); and, second, that which has reached its present position through the action of water, wind, or glaciers.

Where is there the least mantle rock? Where is it the thickest? What would you expect to be the nature of the mantle rock overlying crumbling shale or slate? What kinds of rock will produce a sandy soil? Describe the origin of the mantle rocks of the lowlands.

The mantle rock never has exactly the same composition as the solid rock from which it was derived, for there is a slow removal of soluble materials, as well as the finer and lighter particles. Granite produces a sandy soil, because the clay, arising from the decay of the feldspar, is more easily carried away than the quartz grains. In regions underlaid by limestone, the mantle rock is not composed of the fragments of the limestone, for the latter wastes away by solution rather than by crumbling, but is formed by a gradual accumulation of the impurities which the rock contains.

In the removal of the accumulating mantle rock from the steeper slopes and its deposition over the flood plain, the water acts in a selective manner; it picks up first and carries farthest the finest and lightest material.

Explain the distribution by a stream of the different minerals in decaying granite. Of what material are stream deltas composed? Answer from your own observations.

The wind also sorts the waste of the rocks, but carries only the finest particles to any great distance. In the arid regions of the Western plains and plateaus the wind acts an important

part in the formation of the mantle rock. It is thought that many deposits of fine silt-like material, known as *loess*, are due to the wind. Loess forms one of the richest of soils.

While running water has formed accumulations of great extent and depth in delta regions, ice in the form of glaciers has left vast quantities of transported material strewn over the

FIG. 83.

A cliff of boulder clay. North Manitou Island, Lake Michigan.

surface in the cold latitudes. Glacial deposits cover the bed rock to a considerable depth over large areas lying southwest of the Great Lakes. *Till* is the name given to such deposits when they consist largely of clay with which are mingled boulders and angular rock fragments (Fig. 83). The glacier is not selective in its action, but picks up and bears along everything which lies in its path, finally dropping the rock fragments, big and little mixed indiscriminately, in the form of hummocks and ridges (Fig. 84).

If your home is in a glaciated region, compare the character and manner of arrangement of glacial materials with those which have accumulated under water, noting carefully the resemblances and differences.

The Soil. — The soil must be distinguished from simple rock waste, or mantle rock. Disintegrated rock material is not soil.

FIG. 84.

Section of a glacial moraine, Montana.

The formation of a true soil from rock waste is a slow process, brought about through the decomposition of its minerals and the enrichment of the material by the means of plant and animal life (Fig. 85).

Fill two pots, one with finely crushed rock and the other with ordinary earth from the garden. Plant some corn or wheat in each and watch the result. Plants must have their food in such shape that it is soluble in water; and there is extremely little of a freshly crushed rock that is soluble. Explain what is shown in the cliff of crumbling granite

in Fig. 86. What about the amount of plant food here, compared with that in the crevices of a less decayed rock?

Take a small quantity of soil from the garden or field and determine its leading constituents in the following manner. Place the material in a dish of water and thoroughly stir it until the decaying plant stems, leaves, and roots appear upon the top. Remove these and wash what remains with small portions of water until the water is no longer muddy, and then examine what remains in the bottom of the dish. Save the

Fig. 85.

Ocean Cliff, San Francisco Bay: showing dark layer of humus-rich soil, three feet thick.

muddy water and let it stand until perfectly clear. Pour off the water carefully, so as not to disturb the sediment in the bottom, and find out of what the latter consists. Now take the perfectly clear water and evaporate it over a fire, and, as the water decreases in volume, place it in a smaller dish. When it is entirely gone, you will probably find a little whitish deposit upon the bottom of the dish. This represents the soluble materials in the soil.

In addition, then, to what can be seen in the soil, — that is, the decaying vegetable matter, the sand, the clay, — there are the

minerals, more or less soluble, such as lime, magnesia, iron, silica, potash, soda, and phosphoric acid, which the plants make use of. It is the organic matter known as *vegetable mold*, containing the nitrogenous compounds, which gives the soil its dark color.

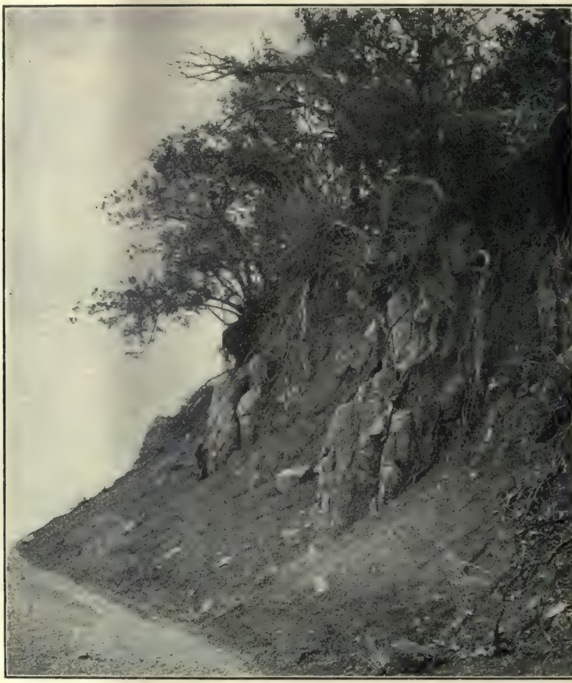

Fig. 86.

Roots penetrating crumbling granite. Arizona.

The mantle rock is also the home of bacteria and other innumerable microscopic forms of life, as well as large ones, such as earthworms and burrowing animals. These organisms, particularly the bacteria, fungi, and earthworms, perform an extremely important part in the transformation of the insoluble rock constituents and vegetable mold into such form that in the presence

Fig. 87.

Roots penetrating the earth, along a parting between layers of upturned rock. Coast Ranges. California.

of water the roots of plants are capable of taking them up and of building them into their tissues.

Fig. 88.
Ant-hill in Mohave Desert.

Beneath the true soil is the *subsoil,* which is lighter colored and less prepared to support the growth of plants (Fig. 85). Here the rock fragments are larger than in the true soil and are replaced in a downward direction by the solid bed rock (Fig. 82). The plant roots in search of moisture do not stop with the soil or the subsoil, but push their way still farther down into the rock crevices (Fig. 87).

The deepening of the soil through exposure to atmospheric

Fig. 89.
Work of the moles in bringing earth to the surface, thus slowly overturning the soil. California.

action is aided in a mechanical way by the ants, who build hillocks of material taken from underground (Fig. 88). The moles (Fig. 89) and all other burrowing animals break up the earth and bring large quantities to the surface, so that in the course of time the mantle rock of areas that they inhabit is completely turned

FIG. 90.

Dike of serpentine, which, because of the poor soil which it forms, supports very little plant life.

over. The falling of forest trees is another means by which buried rock fragments are exposed to the air (Fig. 34).

What are the objects to be accomplished by deep plowing?

As rocks differ in composition, so do the soils which form over them. Some rocks are almost destitute of the materials which plants need, as we can see illustrated by the surface of a dike of serpentine (Fig. 90). This rock contains water, silica, and magnesia as its chief constituents, and furnishes so little soil that

dikes of it can be traced across the country by the partial or entire absence of vegetation.

In localities where the drainage is poor, such as broad valleys or inclosed basins, there is frequently so much soluble material in the soil that plants cannot exist. Such a condition is shown in Fig. 190, taken in the Salton basin, Colorado Desert. Water is obtained here in artesian wells; but even its presence in abundance cannot start life, on account of the quantity of alkali, chiefly sodium carbonate, in the soil.

We must distinguish two kinds of soil, *residual* and *transported.* Residual soil is, like residual mantle rock, that which accumulates from the crumbling rocks beneath. Transported soils are found in valleys and flood plains, in regions of wind deposition and former glaciation.

How is the thickness and richness of soil related to slope? What rocks in your neighborhood produce the richest soil? Beginning with the land in the bottom of a small valley, trace the changes in the soil, in thickness and physical character, up an adjoining slope. Is richness of soil the only reason that vegetation grows more luxuriantly in the valley than upon the hill? Collect a series of specimens from some cliff to illustrate the transformation from rock to soil.

When a new region is settled, the lowlands, unless too wet and densely forested, are settled first. The soil of a flood plain or delta may be said to represent the concentration of all that is best in the soils of the highlands within its watershed. The water takes from all the steeper slopes, unless they are well protected by vegetation, the finest material and that best prepared for plant use. A part of this gathers in the valleys at the foot of the slopes, another part reaches some river and is either dropped upon its flood plain at times of high water or is carried out to sea. The flood plain is thus built up by the addition of successive layers of silt and decaying plant remains, until the material forms a very thick deposit. In the steep banks which a stream sometimes cuts in its flood plain, we can see the manner of

its formation (Fig. 91). Each dark layer represents a period covering a number of years of luxuriant plant growth, and each succeeding light-colored layer a period of rapid accumulation of clayey silt.

The soils of valleys and delta regions are the richest known but they may become impoverished if the same crop is raised upon them for many years in succession.

FIG. 91.

Layers of humus soil alternating with light-colored clayey layers.

In what sort of country did the early civilizations of Asia and Africa develop? What is the object in plowing a field and letting it lie fallow for a time? What is the object of rotating crops in a given field, rather than growing the same ones year after year?

Nature is constantly enriching the soil by means of the moisture which, creeping upward, brings with it plant food in solution. The soil is also enriched through the chemical and physical operations of the organisms which inhabit it.

The artificial enrichment of the soil consists in the application of the nitrates of soda and potash, phosphates (the latter being contained in bones and guano), lime, and gypsum. Some soils need one of these substances, some another. The excess of alkalies in soils can sometimes be neutralized artificially. In regions where irrigation is practiced, the alkalies may be removed by the water, when there is good drainage.

What do you find upon the surface of the ground where there is much alkali in the soil?

On the other hand, where the drainage is bad, it sometimes happens, after several years of irrigation, that soil once very productive becomes so filled with alkalies that plants will no longer grow.

Supposing the water which is turned upon the land is fairly pure, where do these substances come from? You will be able to answer this question by taking some fine sandy loam or clay and mixing a little soda with it while wet. Place it in a box and let the top dry, but keep the bottom moist. Observe if there is a gradual accumulation of soda at the top. Has capillary action anything to do with the upward movement of moisture in soil? Why does the farmer keep the surface of the earth in a loose condition? What effect does the hardening of the top have upon the movement of the moisture below? From observations in the field or experiments, determine what kinds of soil permit the freest movement of moisture. What soils dry out most rapidly and need the most water? What is meant by *light soil?* by *heavy soil?* What is meant by *loam?* What is the composition of *adobe soil?* How does the latter behave when it is drying?

If chemical analysis showed that the mantle rock in a certain place contained the necessary ingredients for plant growth, would that necessarily prove that plants would grow well in it? Give your reasons. Give illustrations of the fact that different plants need different kinds of soil in order to do well.

Find out what you can about the soil of recent glacial deposits. From its manner of accumulation, what would you expect its character to be?

The lowlands of northern Vancouver Island have recently been glaciated, but are now covered with dense forests, owing to the heavy rain-

fall. Where the forest is cleared and the ground burned over, it is difficult to make gardens upon the glacial soil. Can you explain why this is? Would the decay, or oxidation as it is called, of the rock waste go on rapidly where the surface is wet all of the time?

Economic Importance of Different Rock Formations. — Rich soil and suitable climate are the first requisites for the agricultural development of a country.

Compare New England with the Mississippi valley in regard to agricultural conditions and give reasons. How is manufacturing favored by the surface of New England?

Rocks are important as materials of construction. Those are of most value which are easily quarried and shaped, resist atmospheric influences, and possess a pleasing color. The rocks most commonly employed are granite, sandstone, limestone, and marble. Volcanic rocks are frequently used as paving stones. Slate has great value as a roofing material.

Veins of precious metals are confined to the older igneous and metamorphic rocks.

Do such rocks always contain valuable minerals? If not, what is the reason? Compare the mountains of New England with the western Cordilleras[1] with reference to the precious metals. Why are these metals so much more abundant in the West?

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[1] The term Cordilleras is frequently applied to that almost continuous system of mountains along the western borders of both North and South America.

CHAPTER VII.

THE SCULPTURING OF THE LAND.

A Geographic Cycle. — The slow wearing down of all elevated lands and the deposition of the waste in the lowlands and basins has already been described. Review briefly the various agents concerned and the relative importance of each.

In the present chapter we want to get a clear idea of how the land looks at successive periods, as the changes go on. The slopes at each stage have certain characteristics, so that wherever we go, if we understand these characteristics, we can tell whether the features of the landscape upon which we are looking are new or old.

A geographic cycle includes the whole series of changes in the geography of a region, from the time when it is lifted up sufficiently for water and the other destructive forces to work upon it, until it is completely worn down again. A geographic cycle has to do, then, with the birth, the life, and the death of a mountain range or other land form.

The lifetime of a single person, or indeed of many generations, is not sufficiently long to witness the growth of a mountain range and its final disappearance under the attack of the destructive agents, and the question may be asked how it is that these successive changes are known. All mountains are clearly not of the same age, for we can plainly see that some are even now growing while others are nearly worn down. Compare the mountain slopes in the northeastern United States (Fig. 5) with those of the Rocky Mountains and Sierra Nevadas (Fig. 98). It is, then, the study of different parts of the earth that has shown us mountains in all stages of growth and decay, so that we

know what the succession of forms in a given region will be, almost as well as though we had lived a million years, and had actually seen all the transformations.

Conditions Necessary for Erosion. — Winds, waves, and ice have each done something toward the shaping of the earth's surface, but their work is confined to certain places. The almost universal agent is running water. It has done more than all

Fig. 92.

The Santa Catalina range, from Tucson, Arizona.

the others combined. There cannot be running water without sloping land, and for water to do any work, the slope must be of a certain steepness. Then, besides this, we have to take into account the volume of the water and the amount of rock waste which it is carrying.

Answer the following questions as far as possible from your own observations upon the streams of the neighborhood. What are the factors which determine the slope at which a stream will no longer dig its channel deeper? What is the effect of overloading a stream with rock waste? What changes in conditions would cause the gulch in Fig. 47 to be cleaned out by running water? If in one part of a mountain range the rocks decayed very rapidly and in another part the decay was slow, in which would the stream channels first become blocked with

waste rock? Which would have the most rugged and picturesque features?

The Beginning of a River System. — Streams have to make their own channels. A land newly uplifted from beneath the ocean shows none of the details of a surface sculptured by water, details which stand out so beautifully upon the slopes of a mountain range in the early morning or evening (Fig. 92).

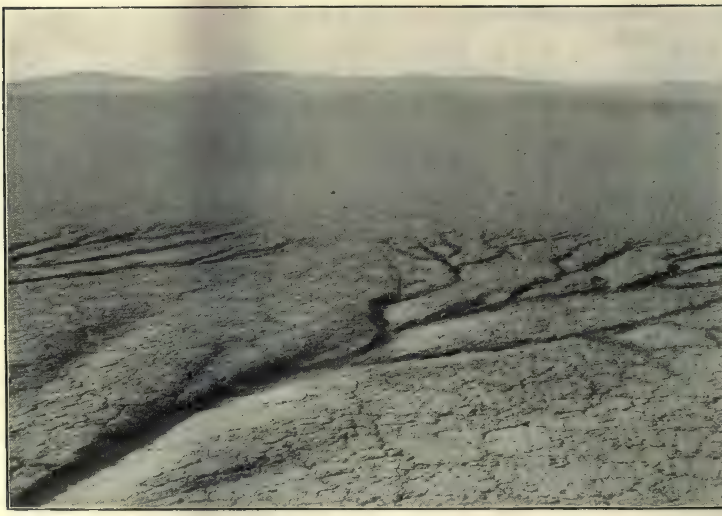

FIG. 93.

Beginning of erosion upon a new land surface: the formation of a river system in miniature. A dry lake bed, Mohave Desert.

While it most frequently happens that new mountains are made from a land surface which, through a long period of erosion, has become more or less worn down to a lowland plain, yet for our study we will deal with a newly uplifted sea floor, since here the conditions are more simple. The lowland plains along the margins of the continents are in many cases portions of a former marginal sea bottom. Such surfaces had, when beneath the water, no drainage lines, no stream channels. They formed

monotonous, gently rolling plains, which had been built up from the slow accumulation of sediments.

Rain falling upon such a surface, newly elevated above the water, flows here and there just as the slopes happen to lead. It gathers in the hollows, forming ponds and lakes; and these, finally overflowing, give rise to streams which flow down this upland to the bordering ocean by the easiest routes possible. The

FIG. 94.

A canyon system in miniature. A valley in New Mexico.

more prominent ridges of the land will determine the watersheds and river systems, but their boundaries are for a long time not sharply defined.

Search for some gently sloping field of hard earth where the water has not yet cut channels and note the manner in which the water collects in the hollows and runs away. Explain the part often played by trails and hill roads in starting gullies.

New Topography. — As soon as the trunk streams have picked out the easiest courses down the slopes and established themselves, the water begins immediately the work of digging channels. For a long time, however, the smaller streams accomplish little, for their courses are poorly defined upon the gentle slopes.

Find out, through the observation of some little wet weather stream, in what part of its course erosion first begins. In what shape does the water flow down a slope where there are no channels? In what portion of the miniature river basin in Fig. 93 did erosion begin? Where was the volume of water the greatest?

Steadily the main streams deepen their channels until canyons are formed. The walls of the canyons, at first steep and rugged, begin to recede under the influence of weathering and erosion, until valleys appear in places.

What influence have the meeting points of streams upon the position of the valleys? Answer from your own observations. To what extent has weathering modified the walls of the miniature canyon shown in Fig. 94? Study carefully the Watrous, New Mexico, and the Yosemite Valley sheets in this connection.[1]

As the deepening of the main canyon progresses, the tributary streams, which at first entered it by a rapid or waterfall, enlarge their canyons also and extend them toward the borders of the watershed. New streams make their appearance upon the upland, branching like the limbs of a tree, until the whole surface is cut up into a complicated system of gulches and flat-topped or gently sloping ridges, which in their even horizon line enable us to picture in our minds the appearance of the former surface. The geographic features of our highland are now in their youthful stage. We say that they are *new* (Fig. 96).

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[1] The topographic sheets referred to throughout the text can be obtained from the United States Geological Survey, Washington, D.C., at a cost of five cents each. Upon application the Survey will send lists of the sheets covering different groups of states. In addition to the sheets mentioned in the text, those covering the district in which each school is situated should always be at hand for study.

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FIG. 95.

You will find examples of new geographic features in many parts of the northern United States where the present stream courses have been in existence only since the melting of the glaciers. Study, in this connection, the Fargo, North Dakota, and Ovid, New York, sheets. Newly elevated coastal regions, as, for example, that along the western border of California, offer abundant illustrations. Examples in miniature of new geographic features occur everywhere and should be carefully examined.

FIG. 96.

The effect of erosion upon an uplifted peneplain underlaid by soft rocks. Salinas Valley, California.

Mature Topography. — Erosion continues its work. The lower portion of the trunk stream in each river system at last reduces its channel to such a gentle slope that farther lowering is stopped. We say that such a stream has become *graded.* Waste accumulates in the channel, the stream begins to meander, and, attacking its banks, assists in the widening of the valleys. This graded condition extends up the stream, reaches the tributaries, and they begin to assume the same character. The water courses eat their way back into the plateau-like upland, attacking the divides from

opposite sides until the latter lose their flat tops and become sharp ridges (Figs. 97, 98).

Refer to the Delaware Water Gap, Pennsylvania, and the Sonora, California, sheets.

The once gently rolling or plain-like upland is now broken into a confused mass of hills and mountains, having completely lost its original character. While in their middle and lower reaches the streams have become graded and the adjoining slopes

Fig. 97.

The uplifted and eroded peneplain of the western slope of the Sierra Nevada Mountains, California.

have lost their precipitousness (Figs. 99, 100), the scenery is still grand and rugged about their head-waters. The streams there dash swiftly through narrow canyons, rapids and waterfalls mark their courses, while jagged peaks rise along the divides. The topography has now reached its *mature* stage.

Study the region in which you live with reference to the stage of geographic development which it exhibits. Such an exercise should include a study of the character of the main stream. Does it flow upon bed rock or upon a built-up channel of silt or gravel? Have the inclos-

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Fig. 98.

Topography in early maturity. Head of the King's River, Sierra Nevada Mountains.

ing highlands gentle or steep slopes? Draw a map of the manner in which some stream that you have observed splits up toward its source. Have the branch streams a swifter current than the main one? Are the divides rounded or sharp? Make a sketch map of the divide between two streams. What makes the line of parting of the waters so crooked? Note if the larger streams have pushed the divide back against the smaller ones on the opposite side.

FIG. 99.

Mature topography. Trinity River, Klamath Mountains, California. This stream is still deepening its canyon.

Explain the convex contour of hills at their tops and the concave character at their bases. What parts of the slopes are due to weathering and what part to erosion? Draw a profile of the channel of some stream which you have examined. In what part is its channel the steepest?

In every locality small streams can be found exhibiting different stages of geographic development in different parts of their courses. One should be chosen and followed to its source, and the features of its channel and slopes which are successively met should be carefully noted.

Fig. 100.

Mature topography: canyon near Phœnix, Arizona. Stream channel has become graded.

In order to illustrate the principles under discussion, a stream should be selected that flows through uniformly resistant rocks the whole distance to be examined.

The Virgin River of Southern Utah offers one of the finest examples known of the work of a stream upon an elevated plateau

FIG. 101.
Kolob Plateau, showing the top of the walls of the Virgin River canyon. Southern Utah.

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FIG. 102.
Broad valley of the Virgin River below the canyon.

region. (See the Kanab, Utah, sheet.) The rocks are homogeneous, and crumble but slowly under the attack of the atmosphere. The surface of the Kolob Plateau is shown in Fig. 101, though the canyons traversing it are so narrow that but little of them can be seen.

We will now follow the Virgin River from the valley below the plateau up through its various stages until it divides into

FIG. 103.

Valley of the Virgin River at Springdale, Utah.

little streams, which as yet have cut only slits in the surface of the plateau. A few miles above the broad valley shown in Fig. 102, the towering walls of the plateau begin to close in. The bottom lands, which are all cultivated, are still more than half a mile wide, the river here having carried its erosion beyond the canyon stage and produced a valley (Fig. 103).

A few miles farther, the walls have come together until there is only a narrow flood plain between them, the cliffs rising in picturesque grandeur to a height of two thousand feet. (See Fig. 1.)

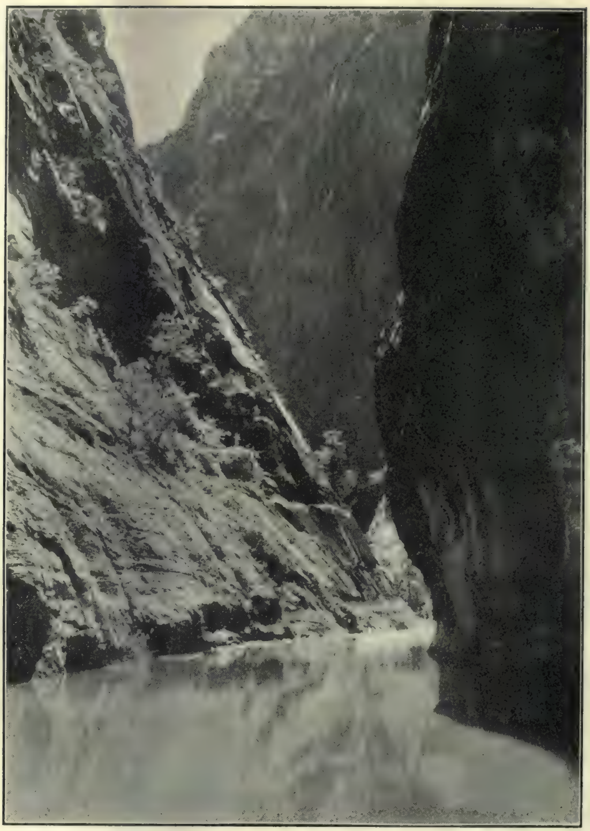

FIG. 104.
The canyon of the Virgin River.

In half a mile more the canyon has narrowed until the stream occupies the whole bottom (Fig. 104). Our last picture is that of the gorge of a tributary stream, representing just the beginning of a canyon in the plateau (Fig. 105).

Could such a canyon ever be formed if the rock disintegrated rapidly? Give your reasons.

FIG. 105.

A tributary gorge of the Virgin River canyon.

This series of pictures illustrates the fact that by following up a stream you may be able to see in succession the various geographic features which would appear one after the other at any particular spot in its course, if you could remain and watch their development through perhaps one hundred thousand years.

Old Topography. — The mountains about the head-waters of streams and along the main divides or watersheds long continue to stand out with rugged features, although the canyons have widened to valleys (Fig. 106). Erosion becomes slower and slower as the slopes of the land grow less. The streams grade their channels still nearer the divides, and the latter lose their sharpness.

Fig. 106.

A desert valley in the southern Sierra Nevada Mountains.

Erosion now almost ceases over the whole area of the former upland. The final stage in the wasting away of an elevated land has been reached. This stage is shown in Fig. 107, representing a portion of the Elsinore, California, sheet. The broad granite plain, broken by low mountains, is a surface of erosion, and is exceptionally free from accumulation of mantle rock, the removal of which may have been aided by the wind. For a farther study of a plain of erosion, consult the Monadnock, New Hampshire, sheet (and see Fig. 178).

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Fig. 107.

A once mountainous region worn down to a plain. Twenty-five miles south of Riverside, California.

A plain such as has just been described may remain indefinitely with little change, until, perhaps, it subsides beneath the ocean or is again lifted to form a new upland. As we shall see later, this wasting away of a mountain range is rarely carried to completion, for new earth movements are likely to occur, lifting or depressing the land; nor is the topography usually simple,

Fig. 108.

View across the Connecticut Valley from Mt. Holyoke, Massachusetts. The even sky-line is formed by the peneplain of New England.

owing to the varying resistance of different rocks to weathering and erosion.

Examine very carefully the features of your home region, and do not leave the subject until you can tell in what stage of a geographic cycle the surface is at present. Look for indications of a former plain, either of erosion or of accumulation, which the streams are now destroying

INFLUENCES WHICH MODIFY LAND SCULPTURE.

Differences in Hardness and Resistance of Rocks. — The features of a region underlaid by hard or resistant rocks will ordinarily be

very different from those carved upon soft rocks. This fact is illustrated in the precipitous canyons of the Kolob Plateau (Fig. 101), and the rounded slopes of Fig. 96.

If soft rocks, such as shale, compose one portion of a plateau, and resistant rocks, like sandstone, another, the former will develop mature features while the latter is still in its youthful stage.

FIG. 109.

Cuesta Pass, Santa Lucia Range, California.

What will determine the position of the mountain peaks finally resulting from the erosion of a plateau of uniformly resistant rocks? What will determine their position if the rocks vary in resistance? Find out from a study of the rock exposures in your neighborhood if there is any relation between the kinds of rock and the position of the valleys. Investigate the streams for the purpose of determining if there is any relation between the narrow portions of their channels, their rapids and waterfalls, and the character of the underlying rocks. Explain in detail the contrasted surfaces shown in Fig. 109.

When a strip of lowland along the coast or at the foot of mountains is uplifted, the streams which immediately begin to flow across it take the most direct course down the slope, excavating parallel channels (Fig. 110). The channels of such streams are determined merely by the slope; they are consequent upon the slope and are therefore called *consequent streams.* If the rocks are uniform in hardness, the streams will keep their original courses, ever burying themselves deeper between their banks.

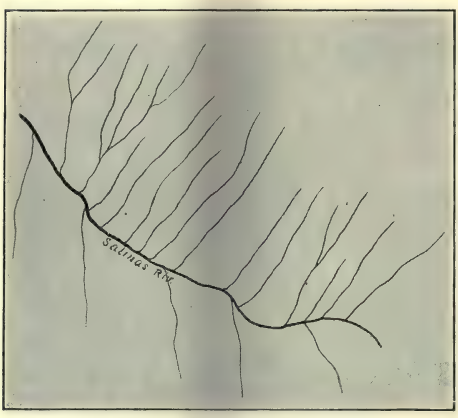

FIG. 110.

Consequent streams which have developed upon a slope underlaid by uniformly soft rock. Salinas Valley, California.

If, on the contrary, the rocks vary in their rapidity of disintegration and resistance to running water, the streams will shortly begin to alter their courses, seeking, as unerringly as though they were possessed of intelligence, the softer rocks and those which offer the least resistance. Their channels are slowly shifted to correspond to the differences in the rocks, and by the time the topography has reached a mature stage the streams have marked out channels which occupy lines of least material resistance down the slope. In position and in the winding character of their courses, after they have become adjusted to the rocks, such streams bear but little resemblance to those which first ran over the surface. They have received the name *subsequent streams* (Fig. 111), because their channels came into existence later than the channels of the consequent streams.

From any reference book, find out what you can about the history of the Appalachian highlands and the peculiar drainage features which they present. What are the reasons for the existence of broad, longitudinal mountain valleys along the tributary streams, while the trunk streams, such as the Delaware and Susquehanna, break through the ridges in narrow "water gaps"? Distinguish here between consequent and subsequent streams. How has the drainage been influenced by the structure and resistance of the rocks?

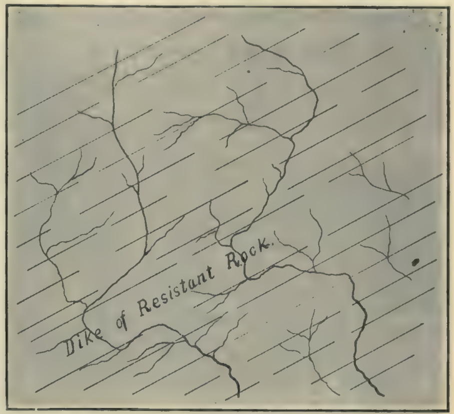

FIG. 111.

Subsequent streams. Sierra Nevada Mountains. The parallel lines show the course of the rock layers.

If we should study the country through which subsequent streams are flowing, we should find that when they encounter a broad stratum or dike of resistant rock, they turn and follow along the softer beds by the side of the hard stratum until a narrow or weak spot is found in it, and then they turn and cross. The channel at such a point is likely to be marked by a rapid or waterfall. The Yellowstone River, in excavating its channel back toward the lake, encountered two dikes of hard rock, which wore away so much more slowly than the soft volcanic tuffs below them that two beautiful falls came into existence (Fig. 265). When these dikes are cut through, the falls will give place to rapids and the lake above will eventually be drained.

In Fig. 112 are seen the remains of a dike of very hard rock which once obstructed the course of the stream; but during the development of the present mature stage of topography, the dike was cut through and the stream has graded its course so completely that there is not even a rapid here now.

Under the combined influences of disintegration and erosion, the innate strong points as well as the weak points are at last fully expressed in the surface features. The valleys are the result of the presence of soft rocks; the canyons appear at points where the streams have to cross hard rocks; while the ridges in many cases mark the most resistant portions of the surface.

Fig. 112.

Russian River, California. Former location of a waterfall.

If there is no example of a large consequent stream at hand, there are, however, to be found in almost every locality numberless examples in miniature made by wet-weather torrents (Fig. 44), upon slopes from which the protecting covering of grass has been removed. Make a careful study of any streams to which you have access, for the purpose of determining what has controlled the selection of their present courses.

Effect of Rock Structure. — Another important factor which affects the character of the geographic features of a region is the structure of the rocks. In an area underlaid by one kind of rock,

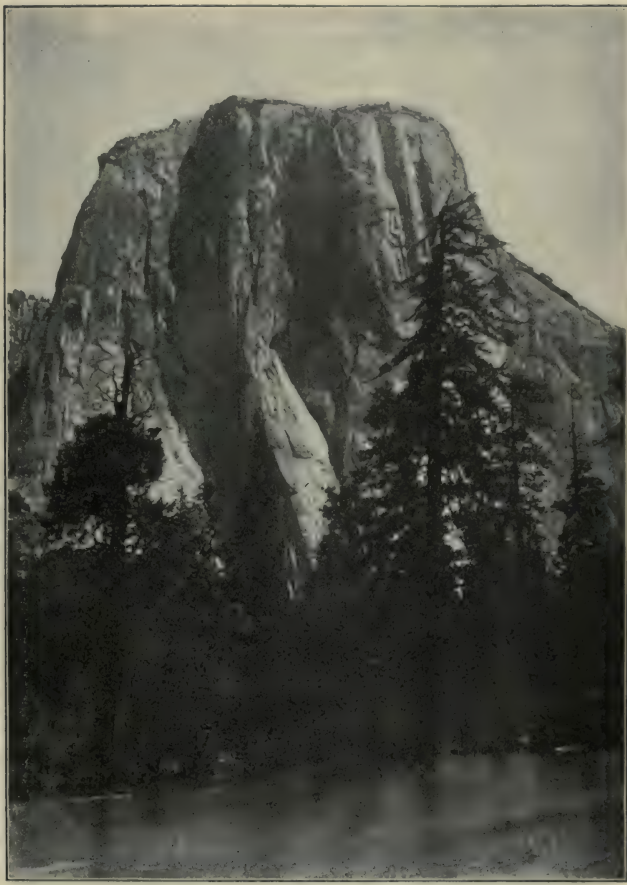

FIG. 113.

El Capitan, Yosemite Valley, California.

such as granite, the character of the peaks and canyons is determined by joint planes, or *zones of fissuring*, if such be present. The precipitous walls in the Yosemite Valley have resulted from the presence of nearly vertical seams in the granite (Fig. 113);

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FIG. 114.

Granite domes above the Yosemite Valley, California. Le Conte Dome (Half Dome) upon the left, Liberty Cap upon the right.

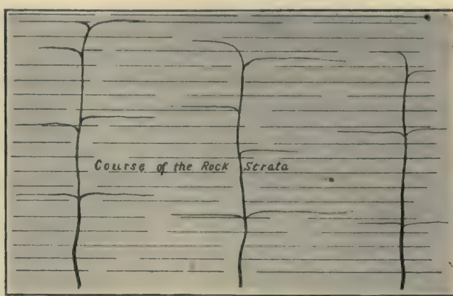

Fig. 115.
Right-angled streams.

while the inclined walls of most of the other canyons in the Sierra Nevada Mountains have developed from inclined seams.

Where jointing is absent, rocks of the granitic type split off in concentric shell-like slabs, giving rounded instead of sharp peaks (Fig. 114). This kind of weathering is called *exfoliation*.

Study the dominant seams in any massive rocks in your neighborhood. Look for joint planes in the stratified rocks and satisfy yourself as to the effects which the presence of these joints has upon the nature of the cliffs of lake or stream.

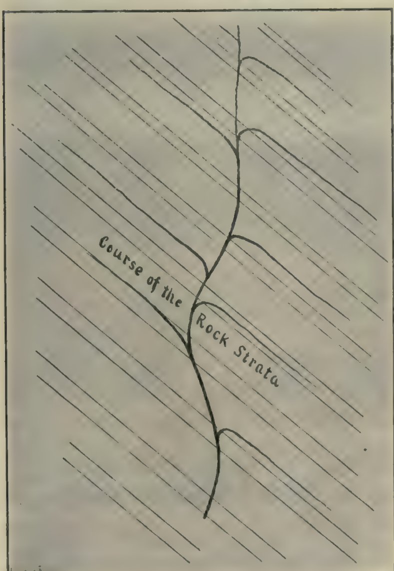

Fig. 116.
Oblique-angled streams.

Position of the Strata. — The position in which the stratified rocks are found, whether horizontal or tilted, has an important influence upon geographic forms. The effects of erosion in horizontal rocks nowhere are more finely brought out than in the high plateau region of Utah and Arizona. Alternations of layers of limestone and sandstone with those of soft shale have resulted in pyramidal or flat-topped hills,

whose surfaces are made up of a succession of steep and of gentle slopes. Alternate layers of hard and soft rocks have also produced the wonderfully terraced and turreted walls of the canyons (Figs. 78 and 304).

As the drainage lines develop in a region of tilted rocks, interesting modifications of the normal features appear. The streams, so far as they are able, adapt their courses to the direction in which the strata extend. Figures 115 and 116 are examples

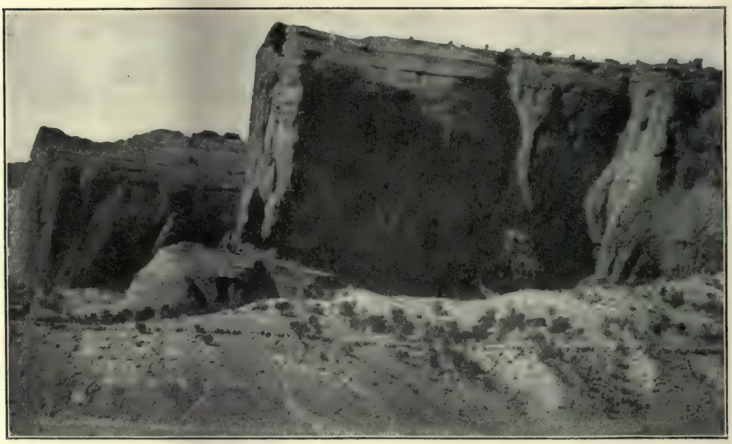

FIG. 117.

Strike cliffs, near Fort Wingate, New Mexico.

illustrating the power of trunk streams to cut their way down a slope across the course of the tilted rock strata. The tributary streams are, however, weaker than the rock structure and have adapted themselves to it, in the one case joining the trunk stream at right angles, and in the other making acute angles upon one side and obtuse angles upon the other.

Streams also slowly shift their channels down the slope of any hard stratum upon which they are flowing, thus tending to undermine the strata lying above. In this manner canyons and valleys

are produced, having steep walls upon one side and gentle slopes upon the other (Figs. 117 and 118). Similar contrasting slopes mark knobs and ridges eroded out of inclined strata (Fig. 120).

Investigate your neighborhood in regard to the position of the strata. Is there any relation between the hard layers and the steep slopes and cliffs? Determine, if possible, whether any of the streams to which you have access flow along the course of the rock layers or seem to pay no attention to them. Will the adaptation of the streams to rock structure

Fig. 118.

Strike cliff and dip slope, near Port Harford, California.

be more complete in a region of new or of mature topography? Will the adaptation be more complete where the rocks differ much or little in resistance?

Climatic Influences. — Climate affects in many ways the rapidity of the destructive forces and the sort of features which they produce.

What is the effect of extremes of heat and cold upon the rocks? In what part of the world are such extremes the greatest? Where are they the least? Why did Cleopatra's Needle, brought from Egypt and set

up in Central Park, New York City, immediately begin to crumble and scale off? Find out what you can about the differences in climate between the two places mentioned. The Needle was finally protected by coating it with a varnish impervious to water. What effect has freezing upon rocks whose seams are filled with water?

Taking into account the fact that with light rain there is little vegetation to protect the rocks and that where the rainfall is heavy vegetation is luxuriant, where will erosion be the more rapid? Would you look for sharp, angular cliffs in a region of light or of heavy rainfall?

FIG. 119.

Effect of erosion upon horizontal strata. Near the Enchanted Mesa, New Mexico.

The peculiar character of the canyons of the western United States, with their precipitous walls, results in part from the climatic conditions, although the position and structure of the rocky strata have also had much to do in producing it.

The Colorado River receives its main water supply in the Rocky Mountains of Colorado and Wyoming, and then, leaving this region of heavy precipitation, flows for hundreds of miles

across a lofty plateau where the rainfall is light and the rocks nearly horizontal.

Illustrate with a sketch the position of the strata and the general character of the canyon of the Colorado, and explain the reasons for the abruptness of its walls. What would you say about the symmetry of the two sides of the canyon, if the strata were steeply tilted?

It might be thought that upon desert slopes where the total rainfall in the year averages less than five inches, the rocks would

Fig. 120.

Effect of erosion upon inclined strata. Garden of the Gods, Colorado.

become buried under an accumulation of crumbling and broken fragments, but such is not the case. Owing to the absence of vegetation, the winds remove large quantities of fine particles; and the occasional occurrence, once perhaps in ten to twenty years, of very heavy rains known as "cloudbursts," has more effect than is usually supposed. The torrents of water, quickly gathering and rushing over the barren, rocky surfaces, sweep everything movable before them and deposit it in the valleys.

Volcanic Eruptions. — Volcanic material is at times forced out upon the earth's surface in such quantities as almost entirely to obliterate the existing features in certain localities. Valleys and canyons are filled and elevations of almost mountain height

Fig. 121.

Erosion of vertical strata. Garden of the Gods, Colorado.

are buried by the fiery floods. Streams are diverted from their channels, lakes are formed (Fig. 313), and entirely new drainage lines are established. Volcanic action has in this manner very greatly modified the surface of the northwestern portion of the United States.

CHAPTER VIII.

EFFECTS OF THE INTERRUPTION OF A GEOGRAPHIC CYCLE.

A Sinking Land. — The crust of the earth is everywhere in almost constant movement, either up or down, though in most places the rate of movement is extremely slow. A continent may be raised or depressed hundreds of feet without any effect being immediately apparent in the behavior of the streams in its interior; but at the points where the streams enter the ocean, and along the coast itself, earth movements of even a very small amount produce features which attract our attention at once.

A sinking of only a few feet results in the flooding of the mouths of the streams and the extension of tidal currents up their channels. The mouth of a large stream will be kept open, but the waves will shortly throw a bar across the mouth of a small one, and the lagoon thus formed will begin to silt up.

Is the sinking of the land more quickly noticeable along a shore bordered by broad plains with sluggish streams, or one bordered by highlands with swift streams?

If the movement amounts to hundreds of feet, the larger streams are flooded for many miles, and then, instead of transporting their load of rock particles to the open ocean, they immediately begin to fill up the submerged portions of their valleys. The effect upon the remaining portions of the streams is to lessen the grade in their lower reaches by the building up of a new flood plain, until an adjustment is reached between the factors of slope, amount of water, and load carried. Unless there is a warping of the land, so that one part sinks more than another, the

work of erosion throughout the greater portion of a river system is not affected. Should the submergence of the land continue, the river systems will be truncated and each of the main tributary streams will enter the ocean through its own mouth.

A sinking of the land along the Pacific coast amounting to about three hundred feet has drowned the lower portion of the Sacramento River, producing the magnificent bay of San Francisco (Fig. 122). Many streams once tributary to this river now empty directly into the bay.

Fig. 122.
San Francisco Bay.

What will be the effect upon the shore line of a sinking land if the country is hilly or mountainous? If it is plain-like in character, what will be the effect? Consult, in this connection, the Boothbay, Maine, sheet (Fig. 123). If the land should be tilted, the coastal portion sinking and that along the divide at the heads of the streams remaining the same height, what would be the effect upon the streams?

What explanation would you give for the presence of islands off the coast of northern New England and the coast of California? Explain the fact that the effect of the tides is felt far up the Hudson River.

A Rising Land. — Let us suppose that in a coastal region of mature topography the land begins to rise slowly.

How would this fact be first recognized? Describe the effect upon the coast line and upon the streams.

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FIG. 123.

After the topography has became *old* in a given region and the trunk stream flows sluggishly through a broad valley, a tilting of the land so as to make its channel steeper, or an elevation of the land as a whole, thus lowering its mouth, will cause the stream to go to work again. Such a stream becomes endowed with new energy and immediately begins to deepen its channel. We say that it is *rejuvenated*, that is, made young again. It will in time, if the upward movement is sufficient, make a new canyon through the center of the old valley. We have then a canyon within a valley, the two features belonging to different geographic cycles. That this is not an imaginary case, the accompanying illustrations will clearly show. In the first (Fig. 124) there is a valley stretching away between the hills toward the ocean. The second (Fig. 125) is a rugged canyon cut out of this valley as a result of an elevation of the land. The valley shown in the first had long passed its graded condition when the uplift came. This movement caused the stream to go to work again, digging the canyon, which is so narrow that only the upper portion can be seen in Fig. 125. The pictures illustrate a portion of the San Luis Rey, California, topographic sheet.

A wet-weather pond will often afford illustrations of the effect of an advancing or retreating shore line upon the mouths of the streamlets entering it.

Should the summits of the hills and ridges in your neighborhood fall into a nearly even plain and the streams cut through this in narrow valleys, what different explanations might you reasonably offer for the origin of these features?

Suppose that some valley with which you are familiar is bounded by hills in which the bed rock outcrops, but that the stream which occupies it is flowing upon sand or gravel, and that wells put down in the valley show the gravel to be very deep, perhaps several hundred feet. What are the different causes which you might with some reason advance for the filling of the old valley that once existed beneath the gravel? Which explanation is likely to be the true one? What change in conditions might lead to a reëxcavation of the valley down to bed rock?

Study the Palmyra, Virginia, topographic sheet as an example of a rejuvenated region.

Superimposed Rivers. — In a region whose geographic features have been drowned by the sinking of the land, the streams, flowing from those portions of the land still rising above the water,

Fig. 124.

The former valley of Temecula Creek, Southern California. In the center of this valley the new canyon shown in Fig. 125 has been eroded.

slowly fill the bays with silt, and, together with the ocean waves, supply sediment which the ocean currents distribute over its floor. As a result, both of the work of the waves leveling off the land while it was sinking and of the accumulation of sediments, the old irregularities of the drowned land largely disappear and a new surface is built up over it.

In the course of time an uplift of the land is almost sure to occur, and then the streams go to work establishing channels in the manner already shown (pp. 128, 144). The streams rapidly cut into the soft sediments, and here and there begin to encounter

the older and harder rocks of the former land. We have learned that rivers will, if they can, shift their channels from any hard rocks in their way to those more easily removed. We might think in the case in hand that when they encounter any of the buried hills of hard rock they would prefer to go around

FIG. 125.

The canyon of Temecula Creek.

them, and perhaps uncover the old channels; but can they do so now? The channels of the new rivers may have sunken hundreds of feet in the soft surface rocks before encountering the hard ones, and now, held in their courses by impassable banks, they are compelled to saw their way through whatever obstacles lie buried

in their paths. Such streams are said to be *superimposed* upon the old land surface.

As the development of the geographic features goes on, the softer beds may be almost wholly removed by erosion, and much of the surface of the older rocks uncovered. Broad valleys

Fig. 126.

Rock stack in the valley of the Mohave River, California.

appear where the streams still flow over the softer rocks; but their passage through the more resistant ones which have been uncovered is marked by rugged and narrow canyons. The streams cannot escape from their canyons to take advantage of the valleys which now open around the knobs of hard rock.

If we did not know the history of the region, this strange behavior of the streams would be most puzzling. To see such a country as it is now, one cannot understand why a stream leaves an open valley, channeling a canyon through a mountain

of hard rock, when it could apparently just as well go around the mountain, following a valley all of the way.

Superimposed rivers may originate in many other places than upon uplifted borders of the continents. A worn-down land upon which stream waste has accumulated so as to bury the rocks will, if uplifted so that water can go to work again, furnish abnormal drainage features. The elevation of the San Bernardino range, California, formed the Mohave River, which, flowing northward into the desert, where great sheets of waste had accumulated, eroded a channel along a line of depressions, and in so doing uncovered a buried hill, which now rises as an island, or rock stack, in its course (Fig. 126).

Many of the great canyons of the West have resulted from the effects of superposition of rivers. Such is the origin of the Black Canyon of the Gunnison River in Colorado. As this is a most interesting case, it will be briefly described.

There existed long ago, in what is now western Colorado, a surface of low mountains and broad valleys formed of granite and ancient stratified rocks. Then came a time when volcanoes broke forth, with the formation of extensive deposits of ashes and other products hurled out during the eruptions. Shallow lakes existed in the broad valleys, and the sediments which gathered upon their bottoms aided further in burying the old land. The new land surface which was thus formed was very different from the old one and gave no indication of what was buried beneath. Mountains had come into existence where there had once been valleys, and valleys appeared where before were mountains.

When the Rocky Mountain region was lifted to its present height and water began to sculpture out the peaks and canyons which we now see, the present streams arose, and among them the Gunnison. There were none of the fertile valleys which now attract the settler, the western part of the state of Colorado being one lofty mountainous plateau sloping westerly toward the Colorado River. The Gunnison followed what was then the easiest

route to its junction with the Grand River, along a depression in the plateau. As it happened, this course was for many miles over a buried granite mountain; but this fact had at first no influence upon the river.

FIG. 127.
Black Canyon of the Gunnison, Colorado.

The stream flowed with a swift current and began to deepen its channel rapidly in the soft rocks of the surface, and finally encountered the granite. The channel was fixed, however, and the river could not escape, so from that day until the present it has been steadily grinding its way down into the granite, producing a canyon now two thousand to twenty-five hundred feet

deep and known as the Black Canyon of the Gunnison, which for the narrowness of the channel and the precipitousness of the walls is but little surpassed by any canyon in our country (Fig. 127).

During the period of canyon erosion the Uncompahgre, a smaller stream, rising in the San Juan Mountains to the south

Fig. 128.
Uncompahgre Valley, Colorado.

and flowing parallel with the Gunnison for some distance before joining it, had also been excavating a channel, but produced a very different sort of one. Its course happened to lie over an ancient valley filled with easily eroded materials, so that a valley has been produced which is not only several miles in width, but is actually lower than the bottom of the Black Canyon of the Gunnison at a point directly opposite. A narrow ridge of granite is all that separates the valley from the canyon. There is now a project on foot to tunnel through this granite ridge and take the

water from the Gunnison for the purpose of irrigating the fertile lands of the valley (Fig. 128), as the stream flowing through it furnishes an insufficient amount of water.

Superimposed streams are found most frequently in mountainous districts and in the formerly glaciated portions of the United States.

FIG. 129.

Black Rock Desert, Nevada.

Learn what you can from some text-book of geology about the preglacial gorge of the Niagara River. In the same connection find out the origin of the Falls of St. Anthony upon the Mississippi River. Give as clear a description as you can of the meaning of the geographic features shown in Fig. 129. This will not be difficult, if you understand clearly what has been discussed in the previous paragraphs.

Warping of the Land. — The movements of the crust rarely amount to the same number of feet for any great distance. One

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FIG. 130.

Fig. 131.
Drainage basin of the Illinois River.

portion sinks or rises more than an adjoining portion, so that gentle folds are formed.

If a movement in a given river system increases the slopes of the streams, what will be the result? If it tilts the country so that the slopes are flatter, what will be the effect upon the streams? Might the warping of the land give rise to basins?

The region about the Great Lakes has long been undergoing a tilting toward the southwest. If this process should continue, it is easy to see that a large portion of their waters will eventually be diverted into the Mississippi River through the Illinois River and the Chicago drainage canal (Fig. 131).

Changes in Climate. — No portion of the earth's surface has always had the same climate.

FIG. 132.

Providence Range and Ivanpah Sink, southeast of Death Valley, California.

Give any proofs of this fact which you have discovered in the study of your neighborhood. Review the possible causes for the change of climate of a given place. How might the change in position of the earth's axis and its distance from the sun affect climate?

A country having an abundant rainfall and with slopes covered with protecting vegetation, will, unless the slopes are very steep, wear down slowly. Will its streams become graded at a greater or less slope than the streams of the arid region where the volume of water is small in

comparison with the amount of rock waste? Explain why the Ohio and Mississippi Rivers, which in their middle courses have a grade less than that of the lower Colorado, are not rapidly silting up.

In the deserts of the Southwest the rainfall was greater at one time than it is now, and many of the valleys which are at present

Fig. 133.

Trenton Falls, New York, a post-glacial gorge.

dry basins, or *sinks*, were then occupied by lakes. The lower mountain slopes about these basins have been largely buried under an enormous accumulation of rock débris which the occasional torrents have collected from the higher peaks and ridges and have spread out about their bases in broad sheets. Except in the mountain gorges where they flow upon bed rock, these streams have no defined channels, flowing here and there in interlacing

courses down the long slopes which they are steadily building up. The water is confined by no banks and at one time or another spreads over the whole surface of the built-up plain (Figs. 132 and 167).

Explain why the torrential streams in the arid region exhibit the peculiarities mentioned.

Glaciation. — In the northern portion of the United States, the glacial period broke in upon a geographic cycle which in most places had passed its mature stage. When the ice melted, the rock débris which it had brought was left strewn over the old land in such quantities as to bury it deeply in places, and give to it everywhere an entirely different appearance.

Innumerable lakes filled the hollows, and the streams of a new geographic cycle began to erode channels, which in the harder rocks are narrow and sharp and marked by numerous waterfalls (Fig. 133). The contrast between the stream channels in the glaciated and non-glaciated portions of the United States is most clearly marked. Contrast the same regions as to relative abundance of the lakes.

The changes brought about in the position of the main rivers were in certain cases very important ones. The St. Lawrence drainage system bears to-day but little resemblance to the pre-glacial one; while other important modifications of the streams about the head of the Mississippi occurred as the result partly of glacial action, partly of the warping of the land.

In the mountains of the West glacial action aided in deepening and widening canyons already in process of excavation by running water, and left many beautiful lakes. The Columbia River was turned from its canyon by a glacier, and, flowing across the plateau of central Washington, cut a remarkable gorge, called the Grand Coulée (Fig. 327). With the melting of the ice the river occupied its old course, and left the coulée to a string of lakes.

CHAPTER IX.

UNDERGROUND WATERS.

Source of Underground Waters. — We have already learned that scarcely any rocks are impervious to water, but that it is absorbed in greater quantity if they are porous or if they are intersected by joint planes and fissures.

Can you tell what two forces are pulling water down into the earth? To show that even massive granite contains water, finely pulverize a small piece, and then weigh a certain amount carefully. Dry this powder for some hours at a temperature not above 100 degrees Fahrenheit, and then weigh it again, to determine the loss.

Water is held mechanically in most rocks, but in such minerals as serpentine, talc, gypsum, and soda it is chemically combined.

Heat a piece of one of these minerals in a glass tube closed at one end, and observe what takes place in the cold portion of the tube.

It has been estimated that the amount of water taken into the rocks would make a layer eight hundred feet thick extending over the whole earth.

What do you think of the quantity now held by the rocks compared with that held by them in the early history of the earth? When the crust was thinner and hotter, could the water go as deep? What prevents the indefinite downward seepage of water?

All springs originate, in the first place, from the coming to the surface of water which, at some time, somewhere, soaked down into the earth. For the sake of convenience, we may say that spring water has two sources. One of these sources is in the rains which fall upon the surface, but do not penetrate to any great depth.

What would be likely to happen to such springs in a given region if a few years should pass without any rain or snow?

The other source of springs is deep in the earth, although in the first place the water must have come from the surface. These springs are supplied directly from what we might call the permanent *ground water.* This water has traveled many miles and has come in contact, perhaps, with heated rocks from which it has dissolved various mineral particles. Such springs are usually more or less impregnated with minerals and are not affected by seasonal changes and droughts. They come to the surface at points where the rocks have been broken by faulting and by volcanic eruptions.

Superficial Springs. — A large part of the rainfall upon a given surface gathers in streams and flows away. The remaining portion sinks into the soil or mantle rock, and is partly used by the plants, partly evaporated into the air, and partly absorbed into the pores and fissures of the bed rock.

Does more rain water soak into the ground during a long-continued drizzle or during a sudden downpour? Describe from your own observations the relative influence of clayey and sandy soils in determining the proportion of rain water that runs away, or the *run-off,* as it is often called. How does the run-off upon a bare surface compare with that upon one protected by vegetation? What effect does clearing the land have upon the run-off? It is a fact that in some districts where the rainfall is abundant there are few springs. How would you account for such a condition? What is the relative ease with which rain water penetrates the mantle rock and the underlying bed rock? You will frequently be able to find, in stream, lake, or ocean cliff, the mantle rock in sharp contact with the bed rock. Seek for springs at the line of junction. Why would you expect to find them here?

Note what rocks appear to take in water readily. Obtain a piece of dry sandstone and weigh it. Immerse it in water for a little time and then weigh it again. This will enable you to determine the proportion of water which the rock has absorbed. If the rock has a specific gravity of 2.25, what proportion in bulk does the absorbed water form?

In cliff exposures seek for joints and seams. Will the water penetrate into the earth most readily in areas of tilted or in areas of flat rocks?

Remember, in this connection, that the different layers of sedimentary rocks differ much in their readiness to absorb water. What rocks do you think are the most porous?

Describe, from what has been given in previous chapters, the effect of heavy showers at rare intervals upon the vegetation and mantle rocks of arid countries. What effect have such climatic conditions upon the springs?

Do you know any springs which flow during only a portion of the year or any which dry up as a result of a drought? What can you say about the depth and extent of their water supply? Supposing the rainfall to be the same in both cases, would you expect to find springs more abundant in a forested region or in one without forests? Give reasons for your answer.

Compare the ease with which water penetrates sedimentary and igneous rocks. Under what conditions would you expect to find springs issuing from granitic rocks? Explain what causes the water to issue as springs after it has once soaked into the ground. Why does it not go directly down into the earth?

Show by the use of a U-shaped tube that water will rise under the influence of gravity just as high upon one side as upon the other.

All bodies of water in the earth having free communication with each other tend to assume the same level. If the passages through the rocks are very small, friction and capillary attraction will prevent water issuing from the ground at a point as high as its source. It has been shown that the pressure of the gas in the deep oil wells in portions of Ohio and Indiana is determined by the elevation of the surface of Lake Superior.

How can you explain the occurrence of a spring on the top of a hill? Find out what relation the springs of the neighborhood bear to the different rock formations. In what situations are the best wells? What is meant by "hard water"? What effect does it have upon soap? What is meant by "soft water"? Some springs contain soda; is this constituent beneficial or detrimental when the water is used for washing purposes?

Try to determine, from a study of hillsides upon which there is little soil, whether certain rocks contain more water than others. Water-bearing strata can frequently be traced by the luxuriant vegetation growing upon them.

In the arid portions of the West, where springs are generally far apart, they are grouped in a most interesting way along the fissures formed during the earthquake movements already described. The borders of dikes of igneous rocks are also frequently marked by large springs. Give reasons for the latter fact.

Mines are generally wet, for the reason that the ore deposits occupy fissures where the crushing of the rocks has left spaces for the accumulation of water. Sometimes water is encountered in such quantity that even the largest pumps cannot keep it out.

We may say in brief, then, that the conditions which favor the penetration of water into the earth are, first, a sufficient rainfall so distributed through the year as to create protecting covering of vegetation; and second, soil and rock waste, together with a bed rock of such character as readily to take in the water which reaches its surface.

Superficial springs, such as we have been describing, are much more abundant, other things being equal, in hilly and mountainous regions than in those nearly level.

If the country were absolutely flat, would there be any springs of this kind? Why do springs occur more frequently upon low land or near the bottom of a canyon than upon high land?

Superficial springs are due, then, partly to the pull of gravity upon rain water which has soaked into the earth and collected in seams and fissures in the rocks, and partly to the presence of an uneven surface, the valleys and canyons of which intersect many of the fissures and thus permit the water to escape rather than continue its course downward into the depths of the earth.

Prepare sketches illustrating the conditions just described.

The Water Table. — Below a certain distance, which varies with the elevation, the climate, and the underlying rocks, we come to permanent water. The surface of this water is known as the *water table.* In the moist portions of the earth, particularly in the tropics and the high latitudes, this is practically at the

surface. In the arid regions it may be as much as two thousand or three thousand feet below, as is shown by the depth at which springs break out of the walls of the Grand Canyon.

When the oxygen of the air attacks substances with which it comes in contact, it is said to *oxidize* them. Iron is oxidized to iron rust; wood decays or is burned in the presence of oxygen. Below the level of permanent water only a very small amount of air can get at the minerals and rocks, so that there is little oxidation.

Report the results of your observations upon the relative degree of preservation of wood and iron which have been under water for a long time, and of similar substances alternately wet and dry.

The changes which take place in rocks and mineral ores when they are exposed alternately to water and air is an important factor in mining. Many ores which in their original condition are difficult to treat in milling operations, are so decomposed above the water line that it is comparatively easy to extract their mineral contents. Such secondary ores are usually carbonates, chlorides, and oxides. Sometimes nature carries this change in the ores still farther and leaves their gold, silver, or copper contents in the pure metallic state.

Describe from specimens the general contrast in character and appearance between the fresh ores of gold, silver, and copper, and their oxidized forms.

Débris Fans as Reservoirs of Water. — Throughout the western portion of the United States there are vast deposits of unconsolidated gravel and sand about the bases of the mountains. These have accumulated because of the inability of the small torrential streams to transport this waste any farther. The streams, upon leaving the rocky canyons of the mountains, spread out upon the slopes of the valleys, drop the loads which they have brought, and then disappear. The loose gravels quickly absorb the water; but, instead of being permanently lost, it is stored by

them away from the dry air. The gravel deposits are often hundreds of feet in depth and many miles in extent, and the amount of water which they are capable of holding is very large.

The water can be easily obtained by wells sunk in the gravels, and in such quantity as to be available for irrigation. The city of Los Angeles receives its water supply largely from tunnels run into the gravels in which a mountain stream sinks at a point fully ten miles distant.

Fig. 134.

Artesian well, in the Colorado Desert, California.

Artesian Wells. — A well in which the water rises to the surface and flows out is called an artesian well, from the province of Artois, in France, where such wells have been known for more than one hundred and fifty years.

What must be the relative elevation of the body of water with which such a well is connected in order to have it rise above the surface? What kind of rock permits water to pass through it most easily, conglomerate, sandstone, clay, shale, or limestone? What is the quicksand that is so often encountered in wells? Would you look for artesian wells in a country of granitic rocks? Give reasons for your answer.

In many ordinary wells such a large flow of water is encountered that they cannot be pumped dry; how would you explain the fact that the water, even if not pumped out, will not rise far above the rocks in which it is found? Are artesian wells ordinarily deep or shallow?

In order for the water to be forced above the surface, it must exist under great pressure in the sands or gravel in which it is found. Consequently it cannot be supplied by rain water penetrating the ground in the neighborhood of the well. The water

flowing from an artesian well soaked into the ground at some point, perhaps many miles away, upon the slopes of the highlands, and creeping down through the porous strata, at last filled them full; but being inclosed above and below by impervious rocks, it could not escape until a hole was drilled down from above.

What is the explanation of the fact that where many artesian wells are put down near together the water will after a time cease flowing with the same degree of force as at first?

FIG. 135.

A ranch in the Colorado Desert, made possible by the discovery of artesian water.

Artesian wells are obtained in the lower portions of basin-like depressions or along the bases of mountains.

Make a sketch of an artesian basin, showing the position of the strata necessary for artesian wells. Make a sketch showing an underground stream which will not rise to the surface if tapped by a well. It will also be good practice to draw cross sections of different kinds of springs, showing how they are produced.

Find out what you can about the cause for the flowing of oil wells. Have such wells any relation to artesian wells? What can you say about the purity of artesian water?

Fig. 136.
An underground stream.

Underground Rivers and Caverns. — In portions of our country where limestone and volcanic rocks abound there are many underground streams of water large enough to be termed rivers. Water percolates downward through the crevices in limestone, and little by little dissolves and carries away the carbonate of lime. The crevices are often enlarged so as to form underground passages many miles in length (Fig. 136). In the valleys of the

Fig. 137.
Montezuma's well, Arizona. A lake-like sink in limestone. The houses of Cliff-dwellers are built into the walls.

Ohio and Mississippi, particularly in Kentucky and Indiana, these caverns are abundant. Those near the surface frequently cave in, giving rise to the basin-like depressions known as *sink holes* (Fig. 137). Surface streams are not likely to be numerous in a region of caverns.

Salt beds lying near the surface may also give rise to sink holes through the solvent action of underground waters, as is shown in certain portions of Kansas (Fig. 138).

FIG. 138.

A sink hole, western Kansas. Probably due to the removal of a part of a salt bed by solution and subsequent caving in of the overlying strata.

Except for the large streams which have cut canyons for themselves, the surface of the volcanic plateaus of the Northwest is almost destitute of running water. An examination of any one of the deep canyons, such as that of the Snake River in southern Idaho, will show us what becomes of the water which

falls upon these plateaus and upon the slopes of the surrounding mountains.

The walls of this canyon show that the plateau is built up of successive flows of lava (Fig. 139), and that at various points streams of water pour into the canyon, issuing from thin layers of gravel at the contact between two adjoining lava flows. The

FIG. 139.

Canyon of the Snake River below Shoshone Falls. Shows several layers of lava separated by beds of gravel.

two most remarkable of these streams give rise to the Blue Lakes and the Thousand Springs. The latter issue in a perfect torrent of water, which deluges the side of the canyon (Fig. 140).

Caverns left in the lava at the time of its cooling form convenient passages for underground streams. North of Mt. Shasta there is a remarkable cavern of this kind, known as Pluto's Cave, which has been explored for more than a mile. It is due to the

formation of a solid crust over a stream of molten lava. The lava within continued to flow on and thus left the long winding tube. The cavern is in places sixty feet high and fifty feet wide (Fig. 141).

In northeastern California a large stream, known as Fall River, issues from beneath a recent lava flow. The water from one great caldron-like spring is sufficient to run a sawmill.

FIG. 140.

Thousand Springs, Snake River Canyon, Idaho. Water issues from a bed of gravel between two lava flows.

Similar rivers burst out of the lava along the eastern base of the Cascade Range. Their waters are always clear and vary but little in volume.

In the semi-arid regions, an abundant water supply may often be obtained by boring in the dry, sandy beds of the streams. The porous sand is deep and the evaporation upon the surface so great that only at rare intervals is any water to be seen upon

the top of the ground. If the bed rock can be reached at any point in the course of such a stream and a dam constructed, the water will be forced to the surface and is then available for irrigation.

Make a sketch of a lava plateau trenched by a canyon; show the layers of lava, with gravel between them, and the mountain highlands

FIG. 141.

Pluto's Cave, north of Mt. Shasta, California.

lying back. If you have ever visited a water-made cavern, describe its character. What reason have we to believe that the streams in caverns are of surface origin? Might they not issue from deep within the earth? The great volumes of hot water encountered in the mines of the Comstock lode could not have come directly from the surface.

Springs of Deep-seated Origin. — Wherever the rocks of the earth's crust are fissured and broken, water in considerable quantities penetrates far toward the interior. The downward course of such water is finally stopped by the heat; for as soon

as it begins to turn to steam, there is such an increase of pressure that a part of the water is forced back toward the surface.

The part played by these deep-seated waters in originating volcanic eruptions and earthquakes is believed to be very important. The most severe eruptions occur either upon oceanic islands or near the borders of the continents, and it is probable that the opening of subterranean fissures during the movements

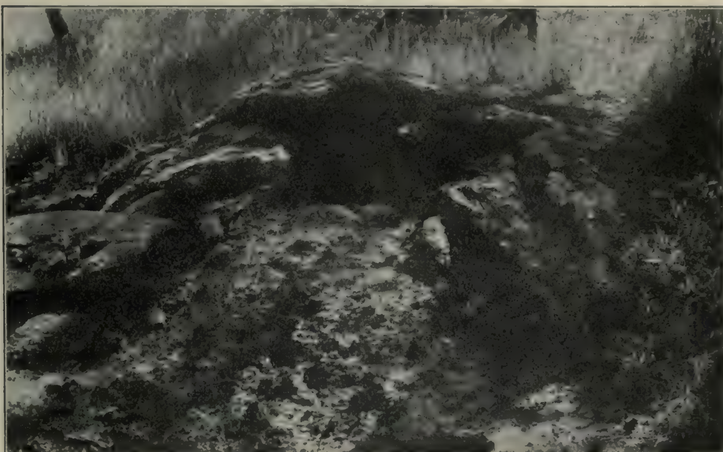

Fig. 142.

Deposits of lime about the orifice of a "soda" spring. Sierra Nevada Mountains.

of the crust permits water in large quantities to come in sudden contact with the heated regions below.

Springs of deep-seated origin issue at the surface either hot or cold; but all such waters must once have been at a high temperature, for they contain in solution many minerals which are not found in superficial springs. Mineral springs continue to flow for a long time after volcanic eruptions have ceased in a given region. They also occur in regions where there have been no volcanic eruptions during the later history of the earth.

If you know of any such springs, describe the nature of the rocks in the country about them. What explanation can you give for their presence?

Some mineral springs are without doubt due to chemical action at some distance below the surface, but still not deep enough to be influenced by the heat of the interior. This chemical action

FIG. 143.

Deposits of the Mammoth Hot Springs, Yellowstone Park.

produces heat, and makes the waters more capable of dissolving many minerals.

Find out what you can about the nature of the country and the origin of the rocks in which occur the geysers and hot springs of Iceland, the Yellowstone Park, and New Zealand.

Are deep-seated springs as likely to be found in desert regions as in moist regions? Does the fact that a spring carries lime, soda, or salt in solution indicate that it is of deep-seated origin? Call to mind in this connection the work of rain water containing carbonic acid.

The chief minerals carried by deep-seated springs are silica, lime, magnesia, iron, potash, and soda. The presence of soda and

carbonic acid in the water of any spring of deep-seated origin enables that water to take into solution many minerals upon which it would otherwise have no effect. The temperature of the water and the composition of the rocks through which it passes are also important factors.

FIG. 144.
One of the "hot pots," Provo Valley, Utah.

In the Yellowstone Park, the spring deposits are either of silica or lime and have resulted in extensive modifications of the surface features (Fig. 143). The "hot pots" of Provo Valley, Utah, form an extremely interesting illustration of the deposit of mineral matter about the orifices of hot springs (Fig 144).

The waters of some of the ancient lakes of the Great Basin contained a large amount of lime, which was gradually deposited as incrusting layers upon rocks and in some cases as domes and towers (Fig. 145).

What explanation would you offer for the presence of so much lime in the lakes just mentioned? If your home is in a region where there are bodies of limestone or marble, seek for deposits made by the superficial springs. Obtain, if possible, an analysis of the water of some "soda spring" and note the variety of minerals present.

The Importance of Springs. — We have come to be very particular, and rightly so, about the kind of drinking water we use,

FIG. 145.

Domes of calcareous tufa, Pyramid Lake, Nevada. Formed in the waters of the ancient Lake Lahontan.

and we feel that spring water, from its long passage through the ground, can contain no surface impurities. Primitive peoples were not so careful about their drinking water; but we must remember that in former times the streams did not become so polluted as they do now in thickly settled and manufacturing districts.

While all springs contain a little mineral matter, they usually offer the best water for drinking purposes that can be obtained.

There are, however, some springs that are so loaded with minerals that they are very harmful. We may say that, as a general thing, the springs issuing from the younger sedimentary rocks contain much more mineral matter in solution than those in regions occupied by the older sedimentary and igneous rocks. The old

Fig. 146.

Deep Hole, one of a group of springs in the Smoke Creek Desert, Nevada. About these springs are grouped the buildings of a cattle ranch.

rocks have gone through so many changes that their soluble constituents have been largely removed.

Where is the purest water usually found, in the mountains or in the lowlands? Give your reasons in full?

Describe any springs you may know of that furnish water which is used for medicinal purposes. Make careful note of all the influences which springs in your neighborhood have had upon the location of homes and the cultivation of the soil.

In the arid regions, springs become of very great importance. They are usually not large enough to form streams which can be led any distance under the hot sun, and their waters are either piped to places where they are needed, or people move to them and build houses and barns about them.

FIG. 147.

Coyote Wells, a stage station in the Salt Wells Desert, California.

The success of mining operations and stock raising in dry countries often depends upon the presence of accessible springs. Mountain springs here form almost the only source of water, for the shallow lakes are usually too much impregnated with various salts to be available.

A spring will, then, determine the position of a ranch house and possibly of a town (Fig. 146). You will find a ranch centered about nearly every important spring in the semi-desert country of the southwestern United States; or, if there is no

surrounding land that will produce anything, the spring may form a stopping place merely, upon some emigrant or mail route. The roads and trails crossing the deserts are always laid out so as to pass as many as possible of the scattered springs near their routes (Fig. 147).

To make this fact clear, study the Camp Mohave, and the Diamond Creek, Arizona, topographic sheets.

The springs, which in portions of the deserts are often thirty to forty miles apart, are difficult to find by those not familiar with the country; but the Indian and prospector must know every one, for upon this knowledge their lives depend.

PART II.

THE PHYSIOGRAPHY OF THE UNITED STATES.

CHAPTER X.

PLAINS.

Introduction.— The previous portion of our book has had to do rather with the forces at work shaping the earth than with the particular results of their work. We are in a position now to understand without difficulty the meaning of typical geographic features. Our study will include a description of only a few, chosen chiefly from our own country; for if we become so familiar with these that we know their meaning, it will not be difficult to extend our knowledge to similar features in other parts of the earth.

There are extensive lowland areas about the borders and in the interior of the continents which present nearly level or gently rolling surfaces, and to these we give the name of *plains.* The streams cross these plains either in shallow channels or, in some cases, with no defined channels, wandering here and there as they grade up the surface with silt and gravel.

As they increase in height and become more deeply trenched by the streams, plains often so blend into *plateaus* that between the two surfaces no sharp distinction can be drawn. On the other hand, plains are not sharply distinguished from *valleys,* for as the latter broaden out they take on a plain-like character. Plains form one of the most important divisions of the earth's features,

partly because of their extent, and partly because of the influence which they have had upon human history.

There are various kinds of plains, each having been formed under conditions which affect its character and determine its importance to man. We may distinguish (1) plains formed by the accumulation of sediments, either upon the land or beneath a body of water, (2) plains of wave and stream erosion, and

FIG. 148.

Scene upon the South Atlantic coastal plain. Near Darlington, South Carolina.

(3) plains of volcanic origin. Plains of accumulation are distinguished by perfectly even surfaces, often many miles in extent. Volcanic plains and plains of erosion are often undulating.

PLAINS OF ACCUMULATION.

Marine Plains.— If you should examine a relief model of North America and the adjoining ocean floor, you would find that the continent is bordered upon the Atlantic coast and along a portion of the Pacific by a submarine plain. Along the Atlantic coast from New Jersey southward this plain, except for a sloping beach and

line of sand dunes, blends with a land plain which extends westward to the foot of the Appalachian highlands (Fig. 148). As we go toward the south, this land plain is seen to embrace all of Florida and the lower portions of the Gulf States.

The materials of the Atlantic coastal plain are sands, clays, and gravels, arranged in layers only slightly consolidated, and containing numerous sea shells. From all these things we must conclude

FIG. 149.

Plain formed by accumulation of sediments beneath the sea. Near Long Beach, California.

that this plain is of marine origin; that it was formed beneath the ocean when the land stood lower than it does at present.

What is the meaning of the long, narrow bays extending into this plain at the mouths of the rivers? There are submerged river valleys crossing that portion of the plain which lies under the ocean. What is the explanation of this fact? Study, in this connection, the Glassboro, New Jersey, the Leonardtown, Maryland, and the Point Lookout, Maryland, topographic sheets (United States Geological Survey).

South of Los Angeles there is an extensive plain formed by a recent rising of the land bordering the Pacific (Fig. 149). Portions of this plain are entirely unmodified by erosion, and, by a very gentle slope, pass beneath the present ocean. A line of sand dunes has been formed along the shore, and back of it there are

FIG. 150.

An ocean cliff, giving a section of the marine plain shown in Fig. 149. Long Beach, coast of Southern California.

marshy tracts. This plain is fertile and highly cultivated where it is not too moist.

Consult the Downey and Redondo, California, topographic sheets.

Now let us see how such a plain can be distinguished from one produced by erosion. At certain exposed points the ocean is now cutting cliffs in this old sea floor, and an examination of these cliffs shows very clearly that the surface of the plain has been produced by the accumulation of sediment, for the layers of sandy clay of which the plain is formed are perfectly parallel

with it (Fig. 150). We may be quite certain that if the surface of the plain were the result of erosion, the layers would not be exactly parallel to it.

There is a series of vast plains stretching from the head of the Gulf of California eastward through Arizona and New Mexico

Fig. 151.
Well boring upon the Staked Plains, Texas.

into Texas, where they form the Staked Plains (Fig. 151). These plains rise from sea level to a height of over four thousand feet on the continental divide; and, while they are dotted with rugged mountains, they form a continuous passageway for one of the Pacific railroads. The waves and currents which built up these plains so long ago distributed the sediments as evenly as a floor. The mountain peaks rise like islands from this floor (Fig. 152).

Across the continent not far above sea level once stretched vast bodies of water, at the bottom of which were deposited

the sediments that made these plains. Toward the west these bodies of water appear to have been connected with the Pacific Ocean through the Gulf of California, and they may have been salt or brackish; but in the region of the Staked Plains there was probably a fresh-water lake, for bones of land animals have been found buried in the materials forming those plains.

From your previous work in geography, hunt out on the map and tell what you can about any other great plains of the world that you think are of marine origin.

FIG. 152.

Picacho Peak. An isolated mountain rising from the plains of southern Arizona.

Lake Plains. — For one reason or another, many large lakes which once occupied various parts of our country have now wholly or in part disappeared and have left in their places extensive areas of level land.

What are the conditions necessary for the existence of a lake? Mention all the causes that you can think of which might lead to the disappearance of a lake. Are there any swamps near your home? If so, study their surroundings with reference to the possibility that they were once lakes. In what part of the United States would you look for the basins of dried-up lakes?

Great Salt Lake lies in the midst of an extensive plain, which is bordered upon the east by the rugged Wasatch Range, while from its desert surface rise almost equally barren mountains. The lake occupies but a tenth of its former area, when, one thousand feet deep and spreading over twenty thousand square miles, it covered a large portion of what is now western Utah. This ancient lake has been called Bonneville, after an early

FIG. 153.

Escalante Desert, southern Utah. Once the bed of Lake Bonneville.

trapper and explorer, and its existence marks a time when the rainfall was much greater than it is at present.

Lake Bonneville was at one time, indeed, a body of fresh water; for it overflowed the rim of mountains and poured a mighty torrent northward through Red Rock Pass (Fig. 309), into the Snake River. Then the climate became drier and the lake began to shrink. Its shores crept down the slopes, not at a steady rate, but with periods of rest, and at every resting time the waves formed beaches which are still well preserved. As the water

retreated, the plain-like floor of the lake, which had all this time been accumulating sediments, was gradually exposed until only the present lake was left. Now the water, nowhere more than forty feet deep, bids fair to disappear entirely, leaving in its place a vast salt-covered plain. Much of the bed of Lake Bonneville, stretching many miles to the south and west of the present lake,

Fig. 154.

Harvesting in the Red River Valley, northwestern Minnesota. This was formerly the bed of Lake Agassiz.

is so utterly barren as to have received the name of the Great American Desert.

This is, then, a plain of accumulation which, with its evenness, great extent, and island-like mountains, reminds one of the surface of the ocean. No other lake plain of such extent and exhibiting so perfectly its original condition is to be found in our whole country (Fig. 153). The soil of the desert shown in this illustration is rich, but probably it can never be used, because of the lack of water in all the surrounding region.

There was at one time a large body of water occupying what is now the valley of the Red River, a stream flowing north along the boundary between Minnesota and Dakota. This extinct lake is known as Lake Agassiz, and probably existed at about the same time as Lake Bonneville.

Lake Agassiz was formed as the result of a glacial dam upon its north side and was drained when the glacier melted. The water of the lake must have been rich in sediment, if we can judge by the thickness of the beds which were formed. This plain of accumulation is now one of the most productive portions of the Northwest (Fig. 154).

Consult the Fargo, North Dakota, topographic sheet in connection with the discussion of Lake Agassiz.

Stream Plains: Deltas. — There is another class of plains which it is not always easy to distinguish from those which have just been described. Such plains are formed by the accumulation of silt at the mouths of streams or by overflow along their lower courses. They may be called *delta plains*, or simply *deltas*.

You would understand how closely such plains resemble marine plains if you could visit the mouth of the Colorado River and see the plain which the river sediments have built. This delta plain extends beneath the water of the Gulf of California, at such a gentle slope that with the wide sweep of the tides it is difficult to say where the land plain ends and the sea floor begins.

If you were studying the origin of any particular delta and found sea shells in the sediments, what would you conclude as to its manner of formation? If you found the remains of land animals, would you be certain that the material was deposited above the level of the ocean?

Some rivers, such as the Rio Grande, the Colorado, and the Missouri, are always muddy from the silt which they are carrying along, although, like other streams, most of their work is done at flood time.

At what season of the year are the streams with which you are familiar doing the most work? Describe the condition of these streams at different seasons of the year. Describe the miniature delta in Fig. 155, and the conditions under which it was built.

What is the character of the delta material at the mouth of a swift torrential stream? Compare such a delta with that of the Mississippi. You will usually be able to find deltas of different kinds made by wet-weather streams. A delta can be easily made with a stream from a

Fig. 155.

A miniature delta. Mohave Desert, California.

hose pipe and a bank of soft material. Describe the character of the delta shown in Fig 156. Make a cross section sketch showing the level of the surface of the water, the front slope of the delta, and the slope of the stream. Prepare another sketch showing the building of a delta of fine silt. Review the cause for the quicker sinking of silt in salt water than in fresh water (p. 105). What effect do the currents of the lake or ocean have upon the building of a delta?

In which case will a stream build a delta more easily — if it empties into a bay or into the open ocean? Compare, in this connection, the Colorado and Columbia Rivers. Find out all that you can about the

mouth of each of these streams. Give reasons for the great delta built by the former and the absence of a delta where the latter enters the Pacific.

How is the Mississippi situated for delta building as compared with the St. Lawrence? Why has the latter no delta? Find out from the map if there are any other large rivers of the United States which have

FIG. 156.

Delta of a torrential stream. Lake Chelan, Washington.

not built deltas out into the ocean, and determine the reasons for their behavior.

The Mississippi River long ago emptied into the Gulf of Mexico through a great bay which extended as far north as Cairo, Illinois. The river carried an enormous quantity of silt, and in the course of long ages the bay was so filled that with a slight uplift of the continent it became dry land. Then across the former delta the Mississippi built a broad flood plain, which extended from Cairo to the new mouth, perhaps three hundred

miles above where the river now empties into the Gulf. This stretch of three hundred miles has been gained to the continent through the slow but constant accumulation of silt. The Mississippi River, like the Sacramento River of California, is now depositing silt in its channel and slowly building it up, so that at every period of high water disastrous floods occur.

Fig. 157.

High tide in Gray's Harbor, Washington.

Draw a cross section, to scale, of the Mississippi and its banks as shown upon the Donaldsonville, Louisiana, topographic sheet. Study in detail the various features of the map. How would you account for the bayous along the lower Mississippi, and the lakes or lagoons in the flood plains of other streams?

As a result of hydraulic mining in the drainage basin of the American River, California, so much rock débris has been carried into the river that its channel along its lower course has been filled up and thousands of acres of fertile bottom lands buried under a deposit of sand. Some of the streets in the town of

Marysville are now below the level of the surface of the river, which is at that place restrained by embankments.

See the Marysville, California, sheet. Upon this same map note the built-up channel of the Sacramento River, and compare it with that of the Mississippi. Explain the presence of sloughs.

Why are deltas more common in lakes than upon the borders of

FIG. 158.

A tidal flat, Oakland, California. Note the forms assumed by the patches of sea grass.

oceans? Does a sinking or rising land favor the formation of deltas on the open coast?

Along both the Atlantic and Pacific coasts the recent sinking of the land has flooded the mouths of the rivers, sometimes for a distance of many miles, thus offering the best possible conditions for the formation of delta plains. Year by year the silt is dropped in the comparatively quiet waters, until they become shallow enough for the sea grass to obtain a hold (Fig. 158).

This in time gives place to the tidal marshes, and these at last to meadows.

Excursions should be taken to lake or seashore for the purpose of making observations upon the silting up of bays. How is this work facilitated by the bars frequently thrown across the mouths of the narrower bays? Explain in detail the meaning of the phenomena shown in Figs. 157 and 158, and the manner in which the grasses aid in building tidal deltas.

Fig. 159.
Delta of the Skagit River, Washington.

The delta of the Skagit River upon Puget Sound is the most interesting of any upon the northwest coast. The silt deposited by this river has gradually encroached upon the sound until it has built up many square miles of exceedingly fertile land. The surface is too moist for trees and forms a natural meadow, which was very much appreciated by the first settlers, for the country about was heavily forested. As the delta grew seaward, it finally enveloped a number of islands, which now rise as forested hills from the surface of the meadows (Fig. 159).

FIG. 160.
Delta plains at low tide. California.

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FIG. 161.
Mouth of San Luis Obispo Creek, California. Note the ox-bow and cut-off formed by the stream upon its tidal delta.

At the time of the last sinking of the land the lower sixty miles of the Sacramento-San Joaquin Valley were flooded so that the tide waters extended across the Coast Ranges and into the Great Valley of California. The river has built vast delta plains (Fig. 160), which at the coming of the first settlers were annually flooded. These have now been in part reclaimed by levees and form the most fertile lands of the state.

FIG. 162.

Mouth of the Arroyo Seco, Salinas Valley, California. Note the interlacing channels in the sandy bed.

What effect does the annual overflow have upon the flood plain? State as fully as you can the origin of the features in Fig. 161.

As we have already seen, a stream becomes graded first at its mouth. The graded surface goes on increasing in width, and in extent up stream, during the whole period of a geographic cycle. It is evident, then, that the flood plain is gradually extended over both the worn-down land and the delta which

has been built up in the body of water into which the stream empties (Fig. 162).

Make a cross-section sketch of the flood plain and delta deposits and show the slope and position of the bed rock near the mouth of some river.

Débris Cones: Waste Plains. — A débris fan or cone is formed in much the same manner as an ordinary delta, except that it

FIG. 163.

Miniature débris cone. Near Los Angeles, California.

originates upon the land instead of in a body of water. Miniature débris cones can often be found in artificial excavations (Fig. 163), perfectly illustrating, in their manner of formation, those which sometimes extend over miles of country.

Describe the cause of the cutting out of the channel in the bank and the filling at the bottom. Why is the surface called a *cone?* Why is the term *débris fan* appropriate? Explain the reasons for the branching of the stream upon the typical débris fan at the mouth of the canyon in Fig. 164.

Find out from your own observations why a débris cone is very steep in one case and almost flat in another. If you cannot find a miniature débris cone, you can make one with a stream of water from a hose.

The thorough understanding of the formation of a miniature cone will enable you to appreciate the vast, gently sloping plains which have grown up about the bases of mountains in those regions where the crumbling of the rocks is rapid and the rainfall light. Such plains, caused by the coalescing of débris cones, are among the most striking features of the valleys of the western United States. Débris cones form important features at points where a side canyon joins a main canyon, especially if the former carries little water (Fig. 166). They appear also upon the borders of lakes inclosed in hills or mountains.

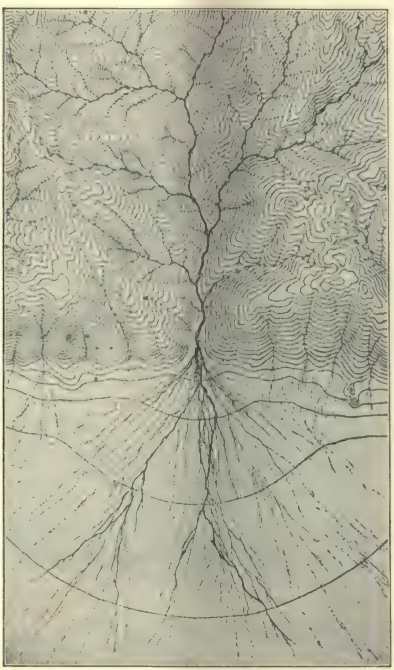

Fig. 164.

Stream branching upon the débris fan, after emerging from the mountains.

Many of the streams in the mountains of the West are of a torrential character, overrunning their banks after the occasional heavy storms, but nearly dry the remainder of the year. At the mouths of the canyons, the flood waters, no longer confined by rock walls, spread out, dropping the coarser fragments of rock waste. The currents sweep over the surface without restraint, excavating a

To face p. 206

FIG. 165.

little here, filling there, but on the whole ever building upward the plain of débris (Fig. 167). Unless the stream is large, it finally sinks in the sand (Fig. 168), forming the vast storage reservoir of water already referred to (p. 173).

Give reasons for the absence of definite channels in Fig. 167.

Fig. 166.

Débris fan at the mouth of a canyon, below Glenwood Springs, Colorado. Note how the débris fan has pushed Grand River to the right.

The débris cones along the foot of a mountain range usually so completely coalesce that they form a true plain, called often a *waste plain* or *waste slope.* In some portions of the arid region one can travel for hundreds of miles and never leave these plains of rock waste, which have accumulated under the influence of torrential streams. They offer easy grades for the railroads which wind through the mountains from one valley to another; but at the same time they have their disadvantages, for when

cloud-bursts occur upon the adjoining mountains, it sometimes happens that the sheets of water, spreading out over these plains, wash away miles of track. The waste plains give a sense of vastness to the desert, being in some cases twelve

FIG. 167.

Tujunga River, San Fernando Valley, California. A typical flood stream of the arid region, without banks or defined channel.

to fifteen miles in length, and having a height at their upper ends two thousand feet greater than at their lower extremities (Fig. 169).

PLAINS OF EROSION.

Introduction. — Plains of erosion are sometimes difficult to distinguish from those of accumulation, particularly in a region of very old geographic features. Usually, however, plains of erosion are more or less undulating, the soil is neither as deep nor as rich as that upon plains of accumulation, and the layers of bed rock appear truncated, instead of lying parallel with the sur-

face. There are two kinds of erosion plains, those formed by waves and those formed by streams.

Wave-cut Plains. — The waves are eating their way into the land with greater or less rapidity along the shores of all large bodies of water. Where the rocks do not differ in hardness, they

Fig. 168.

The Tujunga River, California. The view shows the stream sinking in the sand of its flood plain soon after emerging from the San Gabriel range.

are planed off to a fairly even surface; while resistant masses of rock are left, forming reefs and islands. The work of the waves is more rapid along shore lines where the land is slowly sinking. A portion of the waste of the land is strewn along this marginal sea bottom, forming a covering of varying thickness over the wave-cut plain as the waves extend it landward.

Whenever an elevation of the land takes place, the near-shore portion of the submarine plain is exposed above the water, and

along the new shore the waves begin cutting a lower plain out of the last one (Fig. 170).

Upon the Atlantic side of the continent the plain of marine accumulation has developed upon the largest scale, but along the Pacific, owing to the existence of soft rocks and a recent elevation, we find the best wave-cut plains. The narrow benches which

FIG. 169.

Waste slope in Salt Wells Desert, at the eastern base of the Sierra Nevada Mountains.

the waves left at levels where they worked for only a brief period we call *terraces* (Fig. 346). Where the land stood for a long time at about the same level, the benches cut by the waves are broad and plain-like (Fig. 170).

How does the slope of the land back of the coast affect the rapidity of wave erosion? What kinds of rocks are most easily removed?

If your home is near the coast or a lake, investigate the manner in which the waves do their work and the character of the shelf which they cut in the land. Prepare a cross-section sketch, showing the shore, cliffs, and bottom.

Figure 171 shows what may be seen in many lake or ocean cliffs. The line separating the horizontal beds that form the upper part of the cliff from the tilted beds below is the edge of a wave-cut plain.

Explain the difference in the character of the two beds. Would you judge the surface back of the cliff to be one of erosion or deposition? Give your reasons. Which is the older of the two series of beds? Which

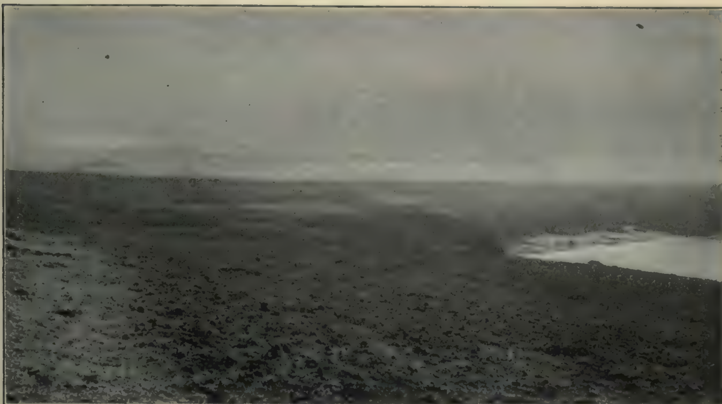

FIG. 170.

A wave-cut plain. Coast of California.

is the softer? Tell as well as you can the history of the two formations in the cliff, and the origin of the three plains, — that at the bottom, that in the middle, and that at the top. What two agents are at work tearing down the cliff? What can you say about the regularity in the layers in the two beds?

Peneplains. — We have already traced the various stages which the features of a region go through during a geographic cycle: the uplift of the land, the active work of the atmospheric agents, the denuding of the slopes by running water, the formation of canyons and rugged peaks, and at last the reduction of the upland to one of low relief (p. 140). A surface so worn down that erosion has almost ceased is called a *peneplain,* meaning that it is almost a plain.

Vast plains border the Rocky Mountains upon the east and

south. From the prairie lands of the Mississippi Valley the ascent to heights of five thousand or six thousand feet along the base of the Rocky Mountains is so gradual that the change in elevation is scarcely noticed. The surface of the Great Plains is for the most part gently undulating, but toward the northwest it is broken by the Black Hills and lesser mountain groups in Montana.

FIG. 171.

A cliff upon the coast of California.

The streams which traverse the plains generally flow in broad, shallow valleys. Toward the base of the mountains gravels are strewn upon the plains, as though the streams at one time had no defined channels; while, as we approach the lowlands of the Mississippi valley, flood plains of considerable breadth make their appearance.

If we could study the rocks underlying the plains, we should find, except in the neighborhood of the mountains, that they are almost flat, and we might at first think that this vast area is an

uplifted ocean or lake floor. A closer examination will show, however, that the surface is not like that of a plain of accumulation. It is everywhere slightly undulating and the rock strata at many points are not exactly parallel with it.

We have no reason to suppose that the region of the Great Plains was originally mountainous, but rather that the folding

FIG. 172.

Looking south from Colorado Springs, Colorado. The scene shows the Great Plains meeting the Front Range of the Rocky Mountains.

upward of the earth along the continental divide raised the plain region also, tilting it into the position it now occupies. The slope was not sufficient for the streams to cut very deep channels, although running water has everywhere worn them down to a greater or less degree. While the main streams are still cutting downward in some places, particularly toward the western border of the Great Plains, yet the region as a whole presents old geographic features.

Study in this connection the Wichita, Kansas, and the Las Animas, Colorado, topographic sheets.

The Black Hills, and many isolated mountain groups of Montana, which rise so boldly from the Great Plains, are not remnants of once continuous mountains, but are, on the contrary, local upheavals of the earth's crust which have been modeled into their present forms by the agents of disintegration and erosion (Fig. 203).

Fig. 173.

The prairies of South Dakota. Note the fringe of trees along the stream.

The relation of the Great Plains to the Rocky Mountains is shown in Fig. 172. The steep slope of the eastern face of the mountains marks the point where the strata, which underneath the plains are nearly flat, have been sharply folded.

The Great Plains merge in an easterly direction into the *prairies* of the Central States. The transition from the plain region to the prairies is marked by a gradual increase in rainfall and deeper, better soil. The name *prairie* was first used by the early French explorers for these treeless areas of the Mississippi Valley (Fig. 173). The absence of trees has been thought to be

due partly to the fact that the fine, rich soil is better adapted to grasses, and partly to fires. A portion of the prairie region is underlaid by *loess*, a fine silt-like material that is believed to have accumulated in shallow lakes which existed here during the melting of the glaciers.

The Great Plains extend entirely across the United States, from north to south. The Staked Plains in western Texas form

FIG. 174.

Pecos River and the rolling plains of New Mexico. Note the scattering growth of scrub juniper trees.

a remnant of an ancient lake bed. They slope gently to the southeast and present a wonderfully even surface (Fig. 151), which is separated from the rolling plains about it (Fig. 174) by an abrupt escarpment upon the west and north. At a little distance this escarpment resembles a line of stakes or a stockade, hence the name.

A remarkable plain-like valley, the product of long-continued erosion upon a once mountainous surface of granite, has already

been referred to (Fig. 107). It is situated a few miles south of Riverside, California. In southeastern California and western Arizona there are very extensive plains of a similar origin. At first sight these plains resemble the slopes produced by the accumulation of rock waste, but a closer examination will show the bed rock hidden just beneath the surface (Fig. 177).

FIG. 175.

Havre, Montana, and the valley of Milk River. The even horizon here is formed by the surface of the Great Plains.

During the long period of the wasting away of the mountains under arid conditions, large areas have been planed off to an even slope by the waste-laden torrents of the occasional heavy rains. When the stream channels have reached a grade at which, with the load they are carrying, downward cutting can no longer go on, they begin to work laterally, widening the graded slope until the divides between adjoining streams are removed. Definite stream channels having now disappeared, the water moves down the slope in the form of a broad, shallow sheet. This is

known as *sheet flood ;* and the plains formed, as *sheet flood plains* (Fig. 177).

Examine any plain-like area, even though it be of very limited extent, in regard to the following points, the best opportunity for observation being offered by the cliffs along some stream or lake. Note the character of the material exposed. Is it arranged in well-marked layers or are the

FIG. 176.

The Great Divide mesa, southern Wyoming. The Great Plains form here the continental divide, with an elevation of over 6000 feet.

layers irregular? Is it coarse or fine in grain? What must have been the nature of the currents which deposited it? Was it deposited on land or under water? Are the layers parallel to the surface or truncated? Is the surface soil residual or transported? If residual, what sort of a plain is it?

Are the streams about your home flowing upon the surface of a plain, or have they cut valleys in an older and uplifted plain? A hill or mountain rising from a plain of erosion is called a *monadnock*. Look for the presence of any such elevations, if there is a plain of erosion within reach. Explain the causes which might produce a monadnock.

Find out what you can about the upland plain of New England. Is it a plain of accumulation or erosion? Give reasons. What kind of rocks underlie this region? Describe the channels which the streams

have worn across this plain to the sea. Where is Mt. Monadnock, and what is its origin (Fig. 178)?

VOLCANIC PLAINS.

Volcanic Plains.—Plains of volcanic origin have a wide extent in the western portion of the United States, but in most cases

FIG. 177.
Sheet flood plains, Mohave Desert, California.

they have been so trenched by the rivers that we might more properly speak of them as *plateaus.*

Molten lava, as it issues from volcanoes or fissures in the earth, is sometimes viscous, like cold molasses, because of its low temperature. At other times it is so hot that it is liquid, and flows almost as easily as water. This liquid lava, when poured out upon a country of hills and valleys, tends to even the surface by first filling the depressions (Fig. 179). If the lava continues to flow out at intervals, there will be successive sheets lying almost horizontally one above the other. The surface of the lava is

Fig. 178.

Mt. Monadnock, New Hampshire, rising above the dissected peneplain of New England.

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frequently marked by small irregularities, due to the cooling and breaking up of the crust; but viewed as a whole it may be almost as even as a sheet of water (Fig. 180).

When the quantity of lava is great, the hills and lower mountains are buried and a plain takes their place. In Fig. 139 is shown the manner in which the lava plain of southern Idaho was made. Several distinct layers of lava can be distinguished.

Fig. 179.

Recent flow of lava upon the summit of the Cascade Range, Oregon. The lava is shown sweeping around hills of the older surface.

Between the periods of eruption the plain must have been occupied by lakes, for thin strata of sand and gravel appear at different points. One is shown along the middle of the cliff.

PLATEAUS.

Introduction. — We use the term *plateau* for any elevated plain-like area which has been more or less cut up by stream channels. The surface of a plateau may or may not be marked by mountain

ranges. As has already been stated, no line of division exists in nature between plains and plateaus, many surfaces partaking of the character of both.

The western half of the United States is characterized particularly as a region of plateaus, many of which are of extreme interest. East of the Rocky Mountains the plateau region blends into the Great Plains, which gradually descend to the prairie

FIG. 180.

Volcanic plain of southern Idaho. The top of the walls of the Snake River Canyon appear in the center of the picture.

lands of the Mississippi Valley. Upon the west the plateaus are bounded by the Sierra Nevada-Cascade system. Of all the area thus inclosed, the Great Basin is least like a plateau, as a portion of it sinks below the level of the ocean.

Study the features of typical plateaus from the Kanab, Utah, and the Watrous, New Mexico, topographic sheets.

Some of the mountain ranges which rise from the plateau of the Cordilleran region are very old and are nearly buried in

their own waste. Among the younger mountain ranges we may include the Wasatch and Uintah, which have been made out of the plateau itself. Thus it has come about that it is not always easy in this region to distinguish between mountains and plateaus. For convenience, we shall speak (1) of uplifted plateaus, and (2) of volcanic plateaus.

Fig. 181.

Canyon of the San Juan River, southeastern Utah. The even surface of the plateau is due to the position of the rock strata.

Uplifted Plateaus. — Under this heading we may distinguish the same divisions as under plains; that is, plateaus of erosion and of accumulation. The plateaus of northern Arizona, Utah, Colorado, and Wyoming form merely a westward extension of the Great Plains, an extension which supports some of the loftiest mountains of the United States. These mountains have grown out of the plateau itself through folding of the strata and through the uplift of certain portions along lines of fracture.

The plateaus owe their distinguishing character primarily to the fact that they are underlaid by level or nearly level rock strata, which do not disintegrate and crumble readily in the dry climate (Fig 101). If the rocks were anything but what they are (chiefly sandstone and limestone) and the layers were steeply tilted, we should not find these extensive flat-topped plateaus with steep-walled canyons cut through them (Fig. 181).

FIG. 182.

The Markagunt Plateau, southern Utah. Elevation 9000 feet.

We descend from the higher plateaus toward the rivers by a series of steps. This is particularly noticeable in southern Utah as we go south from the Markagunt Plateau, at an elevation of nine thousand feet (Fig. 182), toward the Colorado River. The harder rock layers produce flat-topped plateaus or mesas, while the steep scarps or steps, by which they are bounded on their exposed sides, result from the more rapid wearing away of softer underlying rocks, causing the hard ones to break down in cliff form (Fig. 183). A similar succession of precipices and inclines

is seen in the walls of the Grand Canyon. Where the rock layers are slightly tilted, the surface features consist of an alternation of steep and gentle slopes.

Several sketches should be prepared, to show that the relation of surface features to structure of the rocks is clearly understood.

Nowhere else in the world have all of nature's forces so worked together in the production of flat-topped plateaus, cliffs,

FIG. 183.

The Mt. Carmel cliffs. An escarpment upon the Kolob Plateau, southern Utah. Valley of the East Fork of the Virgin River in foreground.

and precipitous canyons. There are the nearly flat layers of rock, the dry climate, the rapid descent to the lowlands about the head of the Gulf of California, and a river system whose supply of water for canyon cutting comes from the distant lofty peaks of the Rockies, where the precipitation is heavy.

Describe the surface features which you think might have resulted if any one of the factors which have influenced the sculpturing of the high plateaus had been different.

Volcanic Plateaus. — The volcanic forces which built up the Columbia Plateau have now apparently ceased their action. At many different periods through long, long ages, molten lava was forced up from the interior of the earth in the northwestern portion of our country, until it spread over, altogether, about six hundred thousand square miles, covering portions of Washington, Oregon, Idaho, California, and Nevada (Fig. 184).

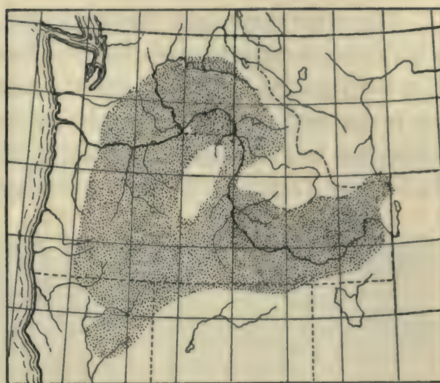


FIG. 184.
Sketch map of the area covered by the Columbia Plateau.

FIG. 185.
Smith's Rock, central Oregon. An ancient mountain peak rising above the level surface of the Columbia lava.

The older lavas have decayed upon the surface, forming rich soils, and stream erosion has in places almost removed them; but the younger lavas still present a surface of low relief, marked by rough and jagged rocks. Mountain-making movements have disturbed and broken the surface of the lava plains, particularly in Oregon, forming lofty and precipitous earth blocks (Fig. 208).

Fig. 186.

Looking across the basin of Shoshone Lake to the Pitchstone Plateau, Yellowstone Park.

The history of the plateau is a long and complicated one. Periods of the outflowing of vast floods of lava and the building of lofty volcanoes alternated with those of quiet, when the country was clothed again in vegetation and lakes marked the hollows of its surface.

The Des Chutes, the Snake, and the Columbia Rivers have cut deep and precipitous canyons, in one case equaling in depth that of the Colorado. The plain of the Des Chutes River, the Big Bend region in Washington, and the plains of southern Idaho

have been but little modified as yet, aside from the canyons eroded in them. The extensive lava fields of southern Idaho are perhaps the most remarkable of all. They stretch nearly four hundred miles from east to west and have a width of two hundred to three hundred miles. For long distances they are almost as level as a floor (Fig. 180).

FIG. 187.
The Enchanted Mesa, New Mexico.

This volcanic plain rises toward the east until it blends with the elevated plateau-like region of the Yellowstone Park. This is situated upon the continental divide, having a general elevation of seventy-five hundred to eighty-five hundred feet. The Pitchstone Plateau, in the southern part of the Park, has an extraordinarily even sky line (Fig. 186).

Refer to the Shoshone, Wyoming, topographic sheet.

Table-lands: **Mesas**. — As a plateau wears away, it frequently happens that small portions of it become isolated by the intersec-

tion of drainage lines, so that they are left for a long time as flat-topped and steep-walled elevations. Such a remnant is called a *table-land*, or *mesa* (Fig. 187). Horizontal rocks whose layers differ in hardness favor the formation of table-lands. Erosion in a region where the surface is capped by a flow of massive lava will result in mesas similar to those in Fig. 188.

FIG. 188.

Volcanic table-lands, eastern Arizona.

Prepare two sketches showing the structure and manner of rock weathering necessary to the production of mesas in the two cases mentioned.

Along some of our coasts there is an uplifted and eroded sea floor to which the name *mesa* has been given. The coast of the extreme southern portion of California exhibits such a mesa, across which the present streams have cut steep-walled valleys, while upon the ocean side the waves have formed cliffs one hundred to three hundred feet in height.

Study in this connection the Oceanside, California, topographic sheet.

CHAPTER XI.

CHARACTERISTICS OF THE PLAINS AND PLATEAUS OF THE UNITED STATES.

Introduction. — If your work so far has been properly done, you should begin to have a clear idea of how much the life of

FIG. 189.

The celebrated Table Mountain, Tuolumne County, California. Table Mountain is the remnant of a lava flow which came down an earlier valley of the Sierra Nevada Mountains. The once higher lands upon either side have been worn away, leaving the more resistant lavas.

any district is dependent upon its geographic environment. You should also be able to understand the fact that the various geographic features are slowly changing at the present time, just as

they have been changing throughout all the long history of the solid earth. The ocean shores have not always been where they are now. Mountains have been worn down, giving place to valleys and plains; while new mountains have been raised up, producing all the diversity of surface which the earth shows to-day.

To make this knowledge of the earth of use, you want to know how the changes of the surface affect the climate and the life of every creature. Animals and plants have become accustomed to the place in which they are living. They may be able to adapt themselves to new conditions, if the climate and food supply change very slowly; but if the changes are rapid, those that cannot migrate to other localities must die.

Every portion of the earth's surface has its peculiar forms of life. Each species is held within certain limits, which it cannot leave without aid.

Mention a number of important animals and plants in any portion of the earth, and the barriers by which they are restrained. Describe all the different kinds of barriers which you can think of, both geographic and climatic. Under what conditions can animals and plants be made to live out of their natural habitat? Find out what you can of the process of selection, by means of which many grains and vegetables of the temperate zone are made to grow in far northern latitudes.

We shall now try to discover the leading characteristics of the plains and plateaus of the United States, noting for what they are most valuable, and the kind of life and industries which they support.

Climate. — Except for the mountain ranges, and the mountain-like plateaus almost as high, nearly the whole area of the high plains of the West possesses an arid or semi-arid climate. The rainfall slowly decreases westward from the Mississippi Valley, varying from ten to twenty inches annually over the greater portion of the plateau region; but in the basin of the lower Colorado it sinks to less than three inches.

The small rainfall over this vast region is due in part to the

fact that high mountain ranges lie between it and the Pacific Ocean, from which come most of the storms. The extreme dryness of the plains and valleys of the southwestern United States results more directly from the fact that this region lies out of the course of most of the storms.

Tell what you can about the rainfall of the Gulf and Atlantic coastal plains. Compare these plains with the Great Plains in regard to the amount of moisture received by them. Give reasons for the differences which exist. Give all the reasons that you can to account for the fact that the Western plains and plateaus possess a great variety of climates. Discuss latitude, elevation, and position with reference to mountains and bodies of water.

Find out what you can about the climate of the plateaus of central Mexico, of South America, and of Asia.

The winter storms upon the Great Plains are severe and often disastrous to life. The vast stretch of open country offers no obstacle to the sweep of the "blizzards." Farther south and southwest there are terrible dust storms. The winds take up the dry, unprotected soil of the deserts, sweeping the finer particles high in the air as a yellow cloud and rolling the coarser ones along the ground. It is fully as dangerous to be caught out in a dust storm, away from water, as to be overtaken by a blizzard.

Aside from the occasional storms, the air of the Western plains and plateaus is clear and dry, but it is marked by great extremes of temperature. During the day the air becomes greatly heated, and at night the radiation is so rapid that there is often a change of fifty degrees during twenty-four hours.

The summers are extremely hot upon the southern plains and deserts, but the air is so dry that the heat is not felt as much as the same temperature would be in moister regions. The winter season upon the deserts is most delightful.

Make observations as to the effect of hills and mountains, or any other barrier, upon the force and regularity of the wind currents. Why is it unsafe sailing upon lakes inclosed by mountains?

Soil. — Portions of the Colorado Desert which were once the bottom of Salton Sea (see p. 122) have a dark, rich soil, but are completely barren (Fig. 190), because of the presence of so much alkali (chiefly soda). In places there is a thin crust of alkali upon the surface. Explain how this was formed.

FIG. 190.

Barren surface of Salton Sink, Colorado Desert. The stream of water is from an artesian well, but owing to the alkali it produces no vegetation.

It sometimes happens that the soils of these old lake beds, when first irrigated, do not show too much alkali, but after a time the water dissolves the soluble salts scattered through the soil and leaves them upon the surface as it evaporates. This soon kills most of the growing plants.

Mention two ways by which the alkali can be gotten rid of.

Review what has already been stated about the soils upon different kinds of plains (p. 122). Find out what you can about the soil of the Atlantic coastal plain and compare it with that of the flood plain of the

Mississippi, in regard to depth and character. Large areas of the coastal plain of the South Atlantic States are covered with pine forests. What does this indicate is the nature of the soil?

Which soil is better prepared for plants and which contains the more humus, that of the flood plain of the Mississippi or that of the sediments once deposited at the mouth of the river under water and at a later time raised to form dry land? Explain fully your conclusions. The study of some flood plain and upland near your home will aid in answering this question.

What soluble mineral substance is likely to be found in the soil of low, poorly drained marine plains? Do you know any particular plants which thrive upon such soils? What mineral substances frequently mark the soils of the beds of dried-up lakes?

The plains of waste formed by the débris fans about the bases of the mountains are, although apparently barren, extremely productive wherever they can be irrigated. These soils contain much more plant food than at first sight would be supposed, because there has not been rainfall enough to wash away the soluble constituents. Owing to the good drainage of such soils, the alkalies cannot accumulate in excess.

Compare the prairie soils of the Mississippi Valley with those of the Great Plains, as to origin, character, and depth. Describe in a general way the distribution of the residual and transported soils of the Great Plains.

The residual soils of the volcanic plains and plateaus are exceptionally rich, for volcanic rocks contain a larger percentage of the elements needed by plants than do most other rocks. Heavy grain crops are produced upon the Columbia Plateau in Oregon and Washington at all points where the rainfall is sufficient. Farther east the plateau region is drier and irrigation is necessary.

Upon the dry plains and plateaus of the West the wind has been an important factor in the making of the soil, although usually its work cannot be clearly distinguished from that of the other soil-making agents. There are, however, certain areas,

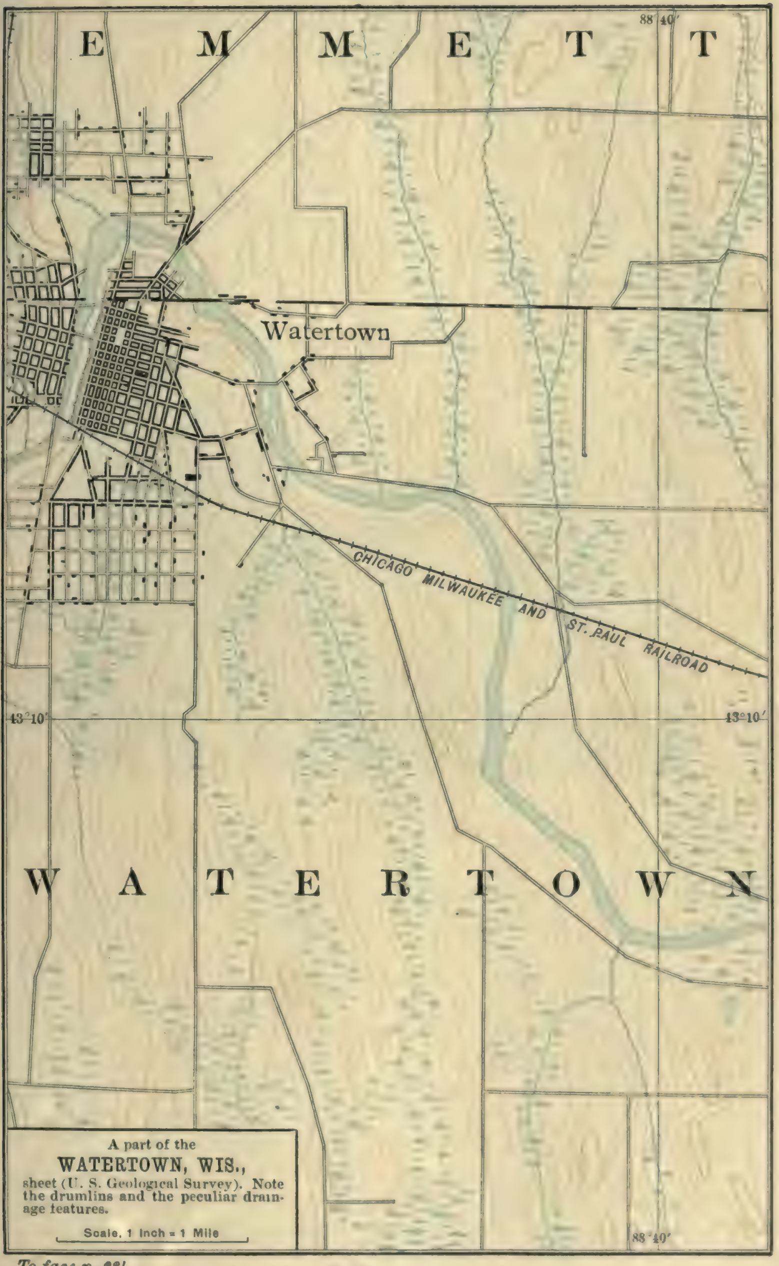
as in north central Oregon, where there are distinct *æolian soils.* Such soils appear not to have been formed as sediments from silt-laden water, nor from the decay of the surface rocks, for they

FIG. 191.

Bad Lands of South Dakota. Sculpturing effect of water upon the surface of the Great Plains.

are separated by a sharp line from the solid rocks upon which they lie.

Underground Water Supply.—The layers of gravel, sand, and clay forming plains of accumulation usually vary somewhat in thickness from place to place, but they have rarely been much disturbed by the forces which have folded and broken the older



To face p. 234

FIG. 192.

rock layers. They are, therefore, from the very nature of such a plain, nearly, if not quite, parallel to the surface.

How does this affect the depth at which water is likely to be found in wells situated at various points upon such a plain? Illustrate your conclusion with a cross-section sketch. Show also by a sketch of a plain which has been worn upon folded rocks the probabilities of obtaining

FIG. 193.

Sod cabin of a settler upon the Great Plains.

water. If well water is obtained in a certain layer of folded rocks, how does the depth at which it occurs vary in different places? Illustrate by a sketch.

Illustrate by a cross-section sketch the position of the strata in a basin-like valley filled with waste from the surrounding mountains, and show the opportunities for obtaining artesian water. Artesian wells are found upon the Atlantic coastal plain. Give the reason for this.

What can you say as to the ease with which water is obtained upon flood plains and deltas compared with uplands?

What can you say about the certainty of obtaining water upon a plain of worn-down igneous rocks? If the soil or mantle rock is deep, where will the water be found in greatest quantity? Illustrate by a sketch your view as to the relative abundance of springs upon a plain of

erosion like the Great Plains, where the valleys are shallow and the strata nearly parallel with the surface. Find out all you can about the main water supply of the Great Plains. In what way do débris fans act as preservers of the scanty rainfall of the arid regions?

From their elevation above the surrounding country and the position of their rock strata, mesas and table-lands are likely to be poorly supplied with water. Water is scarce also upon the surface of volcanic plains, because of the abundance of pores and fissures in the lava. Much of the water gathers in streams far underground and is frequently met with flowing out of the sides of the canyons in large volume (Fig. 140; see p. 178).

Mineral Importance. — We have already learned that the metallic minerals are most abundant along mountain axes, because here their formation is facilitated by the fissures in the rocks, which permit the access of circulating waters to the heated regions below. Because mountains wear down, it is also true that we may find metallic minerals in the rocks underlying plains; but commonly they are buried from sight by younger rocks.

There are, however, many minerals of great value which are found in the rocks of plains, as well as in mountainous areas. Such minerals usually occur in layers between the sedimentary strata, while metallic minerals more commonly occur in fissure veins extending in any direction through the rocks.

The surface rocks throughout the greater portion of the Mississippi basin were formed as sediments in an ocean, lake, or marsh, and contain many minerals of much importance to the development of the country. The strata, however, being usually but little disturbed and the surface of the country gently rolling or plain-like in character, the deposits are rarely exposed upon the surface. In order to find out what is below it is necessary to make borings or sink shafts.

In the Appalachian region, however, and along the eastern face of the Rocky Mountains, the rock strata, with their layers or beds of mineral substances, have been uplifted and folded.

Fig. 194.

The dense forest growth of the Puget Sound region, Washington.

This has given opportunity for the work of the forces bringing about rock decay and erosion, so that after the lapse of ages the mineral-bearing strata have been exposed upon the surface. This condition favors discovery, and permits, in many cases, mining by tunnels, which is cheaper and easier than sinking shafts.

Coal is one of the most widely distributed mineral substances of the Great Central Basin. Petroleum is found in Texas, along the eastern base of the Rocky Mountains, and in the Ohio Valley.

Both gypsum and salt are the products of the drying up of lagoons or lakes whose water once contained these minerals in solution. They are found in Michigan, New York, Louisiana, and in many places over the Great Plains.

Would you expect to find coal upon the Atlantic coastal plain? Give reasons for your answer. Describe briefly the conditions necessary for the accumulation of the organic matter out of which coal is formed. Clay, sand, and marl are found upon coastal plains. Describe the uses of each.

The beds of dried-up lakes throughout the southwestern portion of our country are remarkable for deposits of salt, soda, and borax. In the basin of Great Salt Lake, salt is the chief mineral, although deposits of lime are forming upon the bottom of the lake. In the waters of Owen's and Mono Lakes soda is in excess, with salt next in importance; but in the plain-like basins of the extinct lakes farther south (Fig. 59), there is borax in addition to soda and salt.

The more recent plains and plateaus are without metallic minerals of value, although such minerals do occur in the older lavas, which have often been greatly fissured. Beautiful minerals, such as agate, turquoise, and fire opal, are often found filling cavities and fissures in volcanic rocks. They have been deposited in most cases by percolating surface water, which dissolves the silica of the rocks in one place and deposits it in another. Gypsum occurs in rocks, both as veins cutting across the strata and in beds parallel with them.

Describe the manner of origin in the two cases just mentioned. Are veins as old as the rocks in which they are found? If your home is in a plain region, describe any minerals which are known there and the manner of mining them. Are you familiar with any mineral products of plains of accumulation? If so, describe them and their occurrence.

Describe the advantages or disadvantages which the geographic features of your home region offer for mining.

Agriculture: Stock Raising. — One can tell with considerable exactness the occupations of a people by knowing what kind of climate and geographic features their country possesses.

Upon this basis give in a general way the differences in the occupations of people in mountainous, in hilly, and in plain regions. Illustrate from the United States. Upon a basis of rainfall, temperature, and elevation, discuss the differences between the occupations of people living upon the Atlantic and Gulf coastal plains and those living upon the prairies and Great Plains.

FIG. 195.

Greasewood. Northern Arizona.

Find out what you can about the influence of the delta plains of the Old World upon the location of some of the earliest civilized peoples. Why does the vast region bordering the Amazon River remain unsettled, save for savage Indians?

Are the agricultural products of the Mississippi Valley few or diversified? Why is stock raising relatively less important than farther west?

It is very interesting to trace the influence of increasing elevation and dryness upon the products of the soil and occupations of the people, as one goes westward from the Mississippi River up the long gradual slope toward the base of the Rocky Mountains.

Before reaching the one hundredth meridian the rainfall has so lessened that crops cannot be depended upon without irrigation. The well-watered valleys and prairies with their great variety of products give place to vast grainfields, and these in turn, as the lands become poorly watered, to large areas still unimproved and sparsely settled, over which roam herds of cattle and sheep. Along the river bottoms the land will usually grow grain, but for most products irrigation is employed whenever possible.

FIG. 196.
Sagebrush in the Great Basin.

As we approach the base of the Rocky Mountains, the greater abundance of water from the mountain streams permits irrigation upon a much larger scale; while in places the rainfall is sufficient

to produce some crops without artificial watering. The great elevation of this belt, however, makes it impossible, on account of frosts, to grow many products which do well much farther north in the Mississippi Valley.

A part of the plateau region is too elevated and cold to grow anything except the hardiest plants, even if water were plenty, and here land is of value chiefly as a stock range. The rainfall

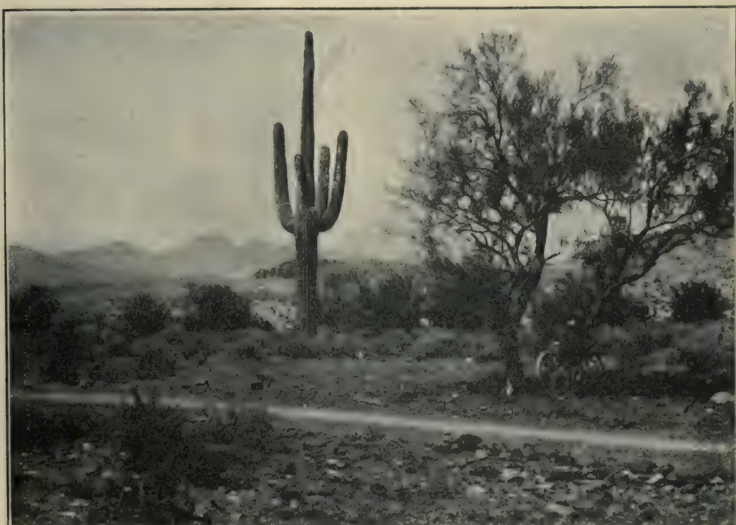


Fig. 197.

Giant cactus and palo verde tree. Desert of southern Arizona.

is unreliable, and during dry years the loss of stock is great. The cattle upon the open plains also suffer severely in the winter storms. The deserts of the southwest are often too dry for grasses or forage plants. In this latter region the development of irrigation, as far as the limited water supply can be applied, is absolutely necessary to settlement.

Vegetation. — It does not matter how rich the soil of a region is, its vegetation will be scanty unless its climate possesses a

certain degree of moisture and warmth. The importance of these two conditions is shown by the existence of the almost impenetrable forest of the tropical lowlands. In the deserts of the southwestern United States the heat is great, but the moisture is deficient; while upon the arctic plains, known as *tundras,* there is moisture, but too low a temperature for the growth of more than a few hardy and stunted plants.

FIG. 198.

Forest of cholla cactus, upon the plains of central Arizona.

Tell what you can about the vegetation of the Atlantic coastal plain. What is the source of the turpentine and resin produced here? Describe the distribution of forests over the Mississippi basin. What are the characteristic trees which fringe the streams of the arid and semi-arid plains? Do you think that prairie fires may have had anything to do with the absence of trees upon the Great Plains?

Tell from any observations which you can make how the distribution of different species of trees and plants is influenced by soil and moisture.

Are the trees of a valley bottom the same species as those upon the upland? Mention all the different causes which might be given to account for the absence of trees upon plains of erosion; upon deltas or flood plains. Can you tell what farm products are especially adapted to the lowlands? Under what conditions is rice grown? Where is it produced?

Forests may be absent from delta lowlands because of too much moisture, as is shown in the case of the deltas about Puget

Fig. 199.

Piñon and yellow pine forest, upon the plateau overlooking the Grand Canyon of the Colorado, Arizona.

Sound, while the higher lands are covered with a heavy growth of trees (Fig. 194).

The vast plains east of the Rocky Mountains are generally grassy. The Great Basin (Fig. 308), portions of the Columbia Plateau, and all the lower plains in the basin of the Colorado have a desert character. They produce but little grass and are in most places covered with different varieties of low shrubs, among

which the greasewood (Fig. 195) and the sagebrush (Fig. 196) are characteristic.

Most interesting are the strange plants which have developed under the heat and dryness of the deserts of Arizona and southeastern California. Here we see with remarkable distinctness the influence which climate exerts upon both plants and animals.

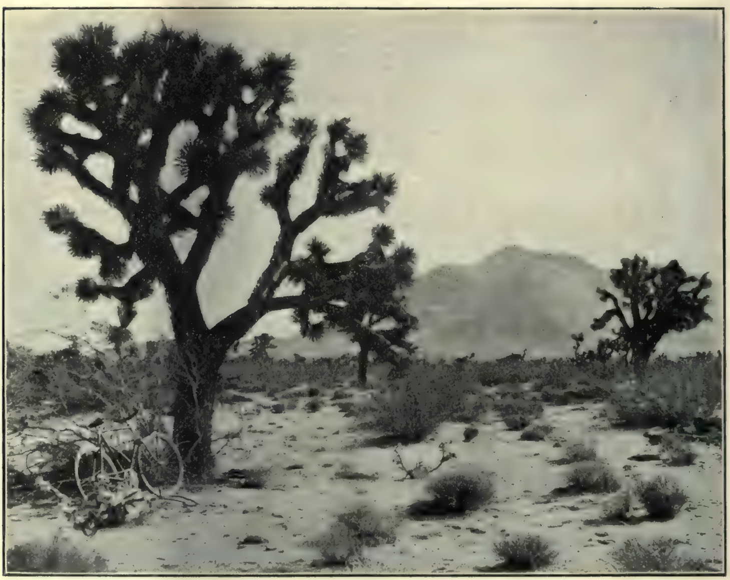


Fig. 200.

Yuccas upon the Mohave Desert.

In order for plants to live in the dry air of the desert, they must not evaporate through stems and leaves their slender water supply. Thus the leaves have decreased in size, and in some cases, as in that of the crucifixion thorn, they have disappeared entirely, only long, slender thorns remaining. Many of the plants that still retain their leaves have become coated with resinous juices, which further aid in the retention of moisture.

The plants of the cactus family are among the most interesting of all the desert flora. Their fleshy stems, armed with various kinds of spines, are able to store up moisture against the long, hot months of summer. The giant cactus forms fairly thick groves over many miles of the plains of Arizona (Fig. 197), and presents a striking appearance with its huge, club-like trunks and symmetrical branches.

Of what use to the desert plants are their spines?

As we ascend toward the high plateau of northern Arizona, the greasewood becomes, at an elevation of about four thousand feet, one of the characteristic plants. Higher still, where the rainfall is greater, are scattered groves of juniper; and upon the Cocanini Plateau overlooking the Grand Canyon there are extensive forests of piñon and yellow pine (Fig. 199). The sagebrush, so abundant over the desert valleys of the Great Basin, sometimes grows almost to the proportions of a tree (Fig. 196).

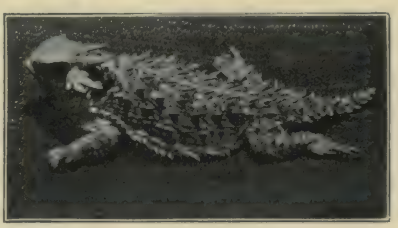


FIG. 201.
Horned toad. A characteristic animal of the desert.

The deserts of southeastern California have a vegetation quite different from that of Arizona. The extensive stretches of sand and gravel are covered with the creosote bush and groves of tree-like yuccas (Fig. 200). Upon the adjacent mountain slopes occur stunted juniper trees; and upon the higher peaks, if the rainfall is sufficient, there may be a few piñon pines.

The animals, like the plants, have become modified to suit their desert life. Each is armed against its neighbor (Fig. 201) in the hard struggle for existence, and has become colored in harmony with the prevailing desert tints. The desert tortoise has even developed a water pocket upon each side under the

shell, so that it may subsist many months far from any water supply.

Deserts form important barriers to the migration of plants and animals. They have separated nations even more completely than have mountains. We can get along with almost all kinds of conditions, except the lack of water.

Trace out upon the map the boundaries of the great deserts of the world, and find out what you can about the causes that have produced them. Study also their vegetation and inhabitants.

Importance in History. — The obstacles to migration offered by barren plains is shown in a forcible manner in the early history of the western United States. It was a long time after settlers had reached the Mississippi Valley before much was learned about the Great Plains and what lay beyond them. This was due partly to the presence of bands of warlike Indians and partly to the character of the streams which, with the exception of the Missouri, could not be followed far in boats.

A century ago the Great Plains had not been crossed; but the mountains which we know as the Rockies had been seen from a distance, and their snowy summits glistening in the sun gave rise to curious myths. One of these is given in Workman's *Geography:* speaking of the ranges of mountains which extend northward from Mexico, it says, "Among these mountains, those that lie to the west of the river St. Pierre are called the Shining Mountains from an infinite number of crystal stones of an amazing size with which they are covered, and which, when the sun shines full upon them, sparkle so as to be seen at a very great distance."

The plateaus and plains of the inter-mountain region are difficult to pass, on account of the lack of water and the existence of precipitous canyons. Both of these barriers aided in keeping the Spanish settlements of New Mexico from spreading northward and northwestward. To the emigrants from the East,

however, the Great Plains offered a fairly easy route as far as the Rocky Mountains; besides, there was grass and water.

In southwestern Wyoming there are gaps in the mountains, and the plains extend practically across the continental divide, so that it was possible on the California route to take wagons as far as the Sierra Nevada Mountains without any great trouble.

The Oregon trail, which branched off at South Pass at the head of the Platte River, was used for wagons as far as The Dalles, although it was difficult crossing the canyons and climbing the Blue Mountains of eastern Oregon. The fact that the emigrant could take his wagon through to Oregon aided greatly in the settlement of that territory and probably saved it to the United States.

The plains and plateaus have had, then, an important influence upon the settlement of the West.

What can you say as to the likelihood of there being good harbors along the shores of a country bordered by a broad coastal plain? Explain the presence of long, narrow bays and a broad coastal plain upon the South Atlantic coast. How does the absence of harbors affect the life of the people?

CHAPTER XII.

MOUNTAINS OF THE UNITED STATES.

Introduction. — Plains impress us because of their horizontal extent. Their even or gently undulating surfaces stretch away to the horizon. Most plains are of slow growth, for they represent the results of the long-continued work of quiet and regular forces.

Mountains interest us because of their vertical extent, and the variety of their slopes and angles. Their bold and picturesque features stand out before us, suggesting invigorating air, dashing streams, and everything that appeals to our love of outdoor life. Among mountains, nature's forces are working more actively than on the plains, not only in building up, but in tearing down.

Review what you have already learned concerning the forces which make mountains.

Now, we want to find out more in detail about the different kinds of mountains. For convenience they may be divided into two classes: (1) those built up by material from within the earth; and (2) those formed by the combined action of the forces within, which lift up the earth's crust by bending and breaking it, and the forces without, which are continually tearing it down by means of erosion.

Lofty mountains are not made all at once, although there are fault blocks in the western United States where it is evident that the earth's crust has been displaced hundreds of feet in a short time. The movements which give rise to mountain ranges are usually slow, and extend through a long period of time during which the destructive forces are steadily at work tearing them down. Hence we rarely have an opportunity to see the work

of the building-up forces in all its grandeur. It is only the recent volcanic peaks and cinder cones that still retain their original forms. In general, the mountains now existing are the

Fig. 202.

Mt. St. Elias, from the Samovar Hills, Alaska. In the middle ground is a vast glacier.

product of the combined action of the building-up and the tearing-down forces; and their individual character is determined by whichever one of these forces is in the ascendency.

MOUNTAINS RESULTING FROM EROSION, FROM FOLDING, AND FROM FAULTING.

Mountains of Erosion or Denudation. — The study of mountains of erosion introduces us to a topic already briefly discussed (Chapter VII).

Review all the reasons that lead you to believe that the upland is wearing down. What is the origin of ravines, gulches, and canyons?

Long exposure of the rocks to decay and erosion has brought into relief all the present hills and mountains. If you could follow back to their beginnings the features of your home landscape, now cut up by a network of streams, you would reach a time when the present drainage lines were not in existence and the surface was comparatively smooth.

The upland of New England is an old plain of erosion which has been uplifted so that now the streams are working upon it

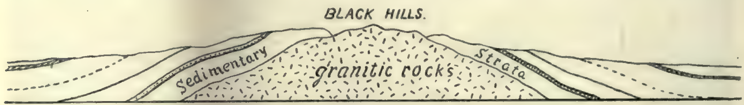


FIG. 203.

Section through the Black Hills.

again (Fig. 178). In time, if undisturbed, they will form a new plain from which will rise hills and mountains of resistant rocks, such as those marking the present upland.

Review the use of the term *monadnock* (p. 217) and the characteristics of the Monadnock, New Hampshire, topographic sheet.

The region of the Appalachian Mountains was once worn down to very low relief. Then an elevation took place and the streams went to work again. We may suppose that at first they followed the steepest slopes; but, since the rocks are folded and differ greatly in resistance to erosion, they soon began to shift their channels, picking out the easiest paths. Now the drainage lines, with the exception of the large rivers, have adapted themselves to the structure of the land, and the region exhibits a series of longitudinal ridges and valleys.

The high plateaus of Utah offer a more interesting illustration of the making of mountains by erosion out of a lofty region of low relief than is to be found anywhere else. Near the divides the streams as yet have not buried themselves deeply in the rolling surface of the Markagunt Plateau (Fig. 182); but

lower down, toward the Colorado River upon the Kolob Plateau, running water is breaking up the once even surface by cutting deep canyons and sculpturing out precipitous peaks (Fig. 4).

Review the features of the Kaibab and Kanab, Utah, sheets.

Other portions of the plateau region, as, for example, that of the Uintah Mountains in northeastern Utah, have been broken by fractures of the crust and elevated so much that erosion has destroyed the plateau features, evolving a truly mountainous surface.

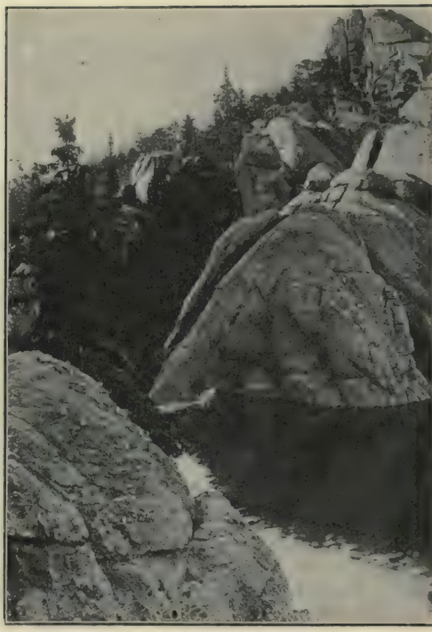


FIG. 204.

Sylvan Lake. The underlying granite exposed by erosion in the heart of the Black Hills.

The picturesque scenery of the Black Hills of South Dakota is due to the results of erosion upon a portion of the Great Plains which has been locally uplifted. This mountain group forms an elliptical area one hundred miles long and fifty miles wide.

We may picture to ourselves a distant time in the past when a portion of the plains began to rise as though some force below was pushing the crust upward. The arching surface was at last high enough so that the new streams began to cut channels. Erosion and elevation went on together, until the strata of shale, sandstone, and quartzite, dipping away in every direction, were cut through and the underlying granite was exposed (Fig. 203).

Now in journeying from the plains toward the center of the Black Hills, we pass successive ridges and valleys surrounding a core of rounded granite knobs and peaks (Fig. 204).

Can you tell what has determined the position of the valleys in the Black Hills?

Fig. 205.

Looking west from the slope of Mt. Whitney toward the Kaweah Range, Sierra Nevada Mountains. In the middle ground appears the old valley of the Kern River, in which its present canyon has been cut.

The grand scenery of the northern Cascade Range in Washington is the work of sculpturing forces upon an ancient plain of erosion which has been lifted to a height of six or seven thousand feet. Here there is no indication of the former plateau-like surface out of which the jagged peaks and ridges (Fig. 375) have been shaped, except in the fairly even sky line which their tops present.

The work of mountain sculpture is not so far advanced in the case of the Sierra Nevada range, and we can easily see that here the streams, aided by the glaciers, have worn deep canyons and precipitous peaks out of an ancient surface once possessing low relief. Some of the canyons, as, for example, those of the Kern and San Joaquin Rivers, have been worn two or three thousand feet deep through the centers of once broad valleys, portions of which now remain as flat-topped shoulders. These shoulders extend back with gentle slope to the rugged peaks along the divides (Fig. 205).

Over the greater portion of our country the only mountains or hills which you can personally study are the product of erosion in a once plateau-like upland. If you live in a hilly or mountainous region, seek for indications of such an upland. Is there any regularity in the heights of the hills and ridges? Mention the possible causes which could account for the presence of prominent peaks rising above a general upland level. During the destruction of a plateau of uniform rocks, at what points on the streams will the canyons first widen to valleys? Make a sketch of some hill formed of soft rocks and show the curve of the slope from the bottom to the top. How do the slopes of such a hill compare with the slopes of a hill of resistant rocks?

Mountains by Folding. — Although the folding of the earth's crust into troughs and ridges is one of the chief causes originating mountains, yet we rarely find a mountain ridge formed of rocks arching upward, or a valley occupying the depression formed by a down fold. The reason for this fact is easy to understand. Just as soon as an uplift begins to affect a region, breaking or bending the strata, the slope of the surface is increased. The steeper the slope becomes, the greater is the power of running water and the more rapid the rate of erosion. While we might expect the streams to flow in the troughs made by folding, yet as a matter of fact they seldom do so, as you can tell by observations of your own.

If we could be upon the ground at the birth of a mountain range, we should at first find the streams flowing in the ready

formed hollows, yet this would be only for a time. We have already learned that streams shift their channels, seeking unerringly the softer rocks, and will in time come to occupy the easiest paths, even though those paths may lie beneath the original mountain fold and involve the wearing away of a vast amount of rock material.

Fig. 206.

The Flatiron Rocks, Boulder, Colorado: showing tilted strata upon the eastern front of the Rocky Mountains.

Go into any hilly or mountainous region where there are stratified rocks, and you will probably find them inclined at almost every angle imaginable. See if you can detect any relation between the folds and the ridges and hollows. Do the land slopes conform in any cases to the dip of the rocks underneath?

The Appalachian Mountains in the eastern United States, some of the ranges of the Rocky Mountains, and the Coast Ranges of California are the best examples which we have of mountains originating by the folding of the earth's crust.

The features of the eastern front of the Rocky Mountains in Colorado show plainly the effects produced by folding. The strata exposed in the cliffs along the shallow valleys of the Great Plains are nearly level; but as we reach the base of the mountains the strata appear abruptly tilted. The steeper slope has given opportunity for the erosive forces to sculpture out of the

FIG. 207.

Beginning of a mountain fold. Scene near Ellensburg, Washington.

harder layers of rock the picturesque cliffs and towers of the Garden of the Gods (Fig. 121). At Boulder, the Flatiron Rocks offer a still clearer illustration of how folding may produce mountains (Fig. 206).

From the volcanic plateaus of the Northwest there have grown many lofty mountain ranges, through the processes of folding and faulting. In Fig. 207 we see the beginning of a mountain fold in Washington. In this particular case the movement undoubtedly stopped long ago, and will never result in a greater elevation.

Explain, from what has already been given, the probable cause of the folding of the earth's crust. Where in the United States have such movements taken place most recently?

Mountains by Faulting. — Although it is hard to realize that the apparently solid earth can be broken, yet earthquakes, and the changes of level of the land which frequently accompany them, show that this actually does take place. The grooved and polished rocks along the fissure (Fig. 17) are proof that the movement may be slow and grinding in its nature, as well as sudden. But whatever the method may be, there result in the end precipitous ridges of such height that we may properly call them mountains. This fact is apparent to any one who has traveled much over the western part of our country.

FIG. 208.

Block mountains. East of the Warner Lakes, Oregon.

The so-called *block mountains* of Oregon, formed by the breaking and displacement of the volcanic plateau, are the most perfect known examples of fault mountains. This is partly because of the resistant nature of the lava and partly because the

fracturing and slipping of the earth blocks have taken place so recently (Fig. 208). We may travel over the gently sloping plains of southern Oregon for many miles, gradually ascending, but with no thought that we are upon a mountain range, until we come out upon a precipitous cliff two thousand feet high and extending for many miles from north to south. At the base of the cliff are marshy lakes occupying the lowest portion of the sunken earth block (Fig. 209).

FIG. 209.

Northernmost of the Warner Lakes, with fault mountains upon the east. Central Oregon.

Examine any cliffs of stratified rocks within reach for examples of small faults similar to that shown in Fig. 18. If the rocks have been much disturbed, you will be almost sure to find some fractures, on the opposite sides of which the rock layers do not exactly match each other. Advance any reasons that you can think of to account for the formation of fissures and the dropping of blocks of the earth's crust.

While folding of the crust has characterized all portions of the continent at some time or other, and while it is also true that rising or sinking and warping of large areas is going on at the present time, yet the latest mountain-making movements have been associated with fracturing and faulting. From the Wasatch and Teton Ranges upon the east to the Sierra Nevada upon the west, displacements of the earth's crust have taken place upon so gigantic a scale as to produce, in connection with subsequent erosion, the grandest scenery in the United States.

The lofty and irregular groups of the Colorado Rockies have been worn out of elevations produced by folding; but such ranges as the Wasatch, with its gentle slope upon one side and precipitous slope upon the other, have a very different origin. Although the Wasatch Range is much worn by erosion, the resemblance to the block mountains of Oregon is so strong that we cannot doubt that it has had a similar origin.

Far back in the history of what we know as the Cordilleran region there were no rugged mountains, merely a lofty, rolling, plateau-like surface. Then there came a time of the appearance of north and south fractures. Some of the great earth blocks settled thousands of feet, as though borne down by their enormous weight; others were raised and tilted as though pushed up from below. The region as a whole between what are now the Sierra Nevada and Wasatch Ranges sank and thus gave rise to the Great Basin, with its many smaller basin-like valleys lying over the blocks which had sunk the most. These events happened so long ago that most of the north and south mountain ranges which are scattered irregularly over the Great Basin have been nearly worn down and have lost their original character as fault mountains. Their waste, unable to escape to the ocean, has gone far toward filling the ancient valleys whose sunken blocks now lie buried thousands of feet beneath these deserts.

Upon the western and eastern borders of the Great Basin there has been a renewal of mountain making, as is shown by

the earthquakes and faultings of the crust which have taken place within the last fifty years. At the base of the Wasatch Range, southeast of Salt Lake City, there is a bluff fully seventy-five feet

FIG. 210.

Recent fault cliff. Base of Wasatch Range, at mouth of Cottonwood Canyon, Utah.

high formed by the dropping of the valley block in this manner (Fig. 210). Behind this bluff rises the precipitous mountain front to an elevation of nearly eight thousand feet above the basin of Great Salt Lake.

More rugged even than the Wasatch Range is the Sierra Nevada, many of whose peaks reach an elevation of over fourteen

thousand feet. This great mountain block, four hundred miles long and seventy miles wide, has been lifted along its eastern side and tilted to the west so that its bold face, rising six thousand to ten thousand feet above the desert valleys, faces east toward the Wasatch Range (Fig. 211). You will perhaps understand the tilting of such a block better by comparing it to a

Fig. 211.

Eastern face of Sierra Nevada fault block. Owen's Valley, California.

trap door slightly lifted at one side and held down at the other by hinges. The long, gentle slope of the door would then correspond to the western slope of the Sierra Nevada, and the abrupt descent to the floor from the upper edge of the door would correspond to the eastern face of the range.

The Teton Range in northwestern Wyoming is another of those remarkable examples which we have in the United States of a block of the earth's crust lifted along a line of fracture and tilted

in the manner just described. It thus closely resembles the Sierra Nevada Mountains and the block mountains of Oregon.

The Teton Range, as viewed from Jackson Lake upon the east, presents an exceedingly steep and rugged face. Although not an extensive mountain range, it is nearly as high as any in the West, reaching an elevation of 13,371 feet. Moreover, it is

FIG. 212.

The Teton Range, from Jackson Lake: showing the precipitous fault scarp deeply worn by erosion.

without doubt the most picturesque of them all. The vertical displacement at the eastern base of the range must be nearly two miles (Fig. 212). The western slope, as seen from Teton basin, presents a most marked contrast with the eastern (Fig. 213).

It should be clearly understood that the magnificent scenery of such a fault block as the Teton Range is only in part a result of the great elevation of an earth block, although such an elevation

is the primary condition. The actual forces which have produced the deep canyons and individual peaks are those of erosion.

Wherever you see in the western United States a mountain wall with steep and rugged slope, you may be quite sure that uplift is either going on, or has gone on in times so recent that the destructive forces have not yet been able to modify it greatly. The less the mountain slope and the broader the valleys, the

Fig. 213.

The Teton Range, from the west: showing the long, gentle slope upon that side.

longer, other things being equal, has erosion been at work without interruption. Compare Fig. 132 of the old topography in the Mohave Desert with Fig. 212 of the Teton Range, and the difference between old and new mountains will be very evident to you.

Study carefully a relief map or model of the Cordilleran region. Locate the Sierra Nevada, Wasatch, and Teton Ranges, and the region of the block mountains of Oregon. Compare these new mountains of the West with the Ozark region of Missouri and the Laurentian Highlands of Canada. High mountains undoubtedly occupied both of the latter regions. What has become of them?

The Laurentian Highlands, extending into the northeastern part of the United States, are thought to occupy the region of the oldest land on the continent. There were probably mountains here while much of the southern and western part of the country was occupied by the ocean. So the changes go on: where the mountains were once lofty, there is now only a plateau-like upland; and where there was an ancient ocean dotted with islands, there is now the most rugged and attractive mountain scenery.

MOUNTAINS OF IGNEOUS ORIGIN.

Introduction. — At one time or another nearly all parts of the earth have been affected by volcanic action. The forces which act from within the earth show their effects in various ways. At one time the crust is folded, at another time it is fractured, and the earth blocks thus formed are lifted or dropped. Along the lines of fracture or folding the earth's crust is weakest, and here molten matter, fragments of solid rock, mud, and gases are expelled, often with the greatest violence. Geysers and hot springs are further indications of the energy within the earth.

Trace out carefully upon a globe the important volcanic regions of the earth, and note what relation they have to the main mountain axes.

Now we want to study in detail the geographic features which result from the action of heat within the earth. Although some volcanic eruptions are believed to result from chemical action, yet probably the greater number are due to the primitive heat of the earth which still maintains the interior at a high temperature. The friction of the rocks rubbing upon each other during the making of mountains also produces heat.

Give some common illustrations of heat from friction; also of heat from chemical action.

We must not think of eruptions as necessarily associated with lofty volcanoes, for the greater portion of the lava which has

buried so much of the earth's earlier surface has come from fissures or low, inconspicuous craters. In fact, even the openings from which lava has flowed are often hidden. Long afterward, when erosion has removed the overlying lava and lowered the general level of the country, we may find the throat of the old volcano, once buried, now exposed as a hill or mountain. If the

FIG. 214.

A volcanic neck, near San Luis Obispo, California.

rock is very resistant, this will rise with great ruggedness (Fig. 214).

Mountains of volcanic origin generally exist as single peaks or groups of peaks, rather than as continuous ranges such as we have learned are the product of folding and faulting. In Oregon and Washington, however, there are exceptions to this rule, for the volcanic plateau has been folded upward, making the Cascade Range. It has also been broken by faults in the region of the block mountains.

The Cascade Range since its formation has been sculptured

by running water into a network of canyons and ridges. Much of the range has still, however, a plateau-like character, and from its summit rise the great volcanic peaks, such as Shasta (Fig. 2), Jefferson, Hood, Rainier, and Baker. Volcanoes are among the most impressive mountains known, partly because of their sym-

FIG. 215.

The interior of a large explosive crater, near Mono Lake, California.

metry and partly because they usually stand out by themselves more sharply than mountains sculptured out of an elevated earth block by erosion. Mt. Whitney, the highest mountain in the United States outside of Alaska, is but a little more lofty than a dozen other peaks in its vicinity ; and one has to obtain a favorable position to see that it is higher than its neighbors. Only the upper three or four thousand feet of these peaks show above the earth block upon which they stand ; while Shasta and Rainier

tower more than ten thousand feet above the surrounding country (Fig. 2).

Volcanic forces have originated many kinds of geographic features, the most important of which we shall now consider.

Explosive Craters. — The simplest form of volcanic eruption is an explosion of gases merely, without the appearance of any

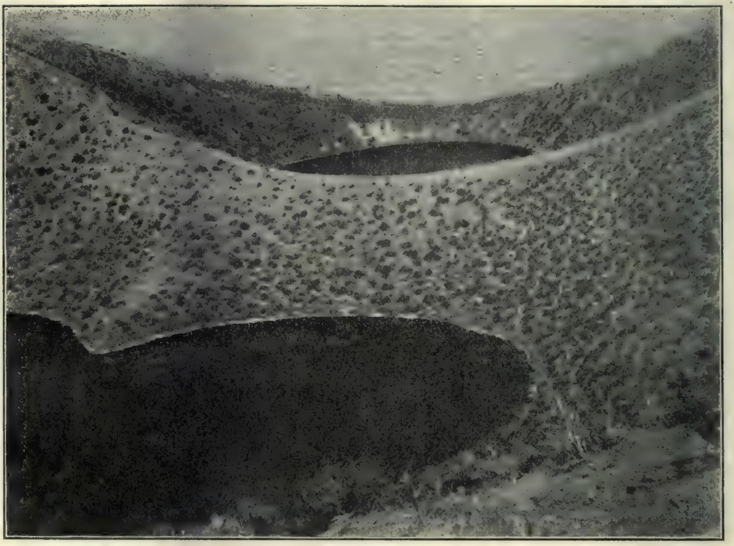


FIG. 216.

Explosive craters, Pa-o-ha Island, Mono Lake, California.

lava fragments, molten or solid. Where a great volume of gas is suddenly formed beneath the crust, it will break through if there is a weak spot, blowing out, with a violent explosion, the rocks at the surface, and leaving a funnel-shaped hole in the ground. Such an opening is a true crater, although it may not correspond to the picture of a crater which we have formed in our minds.

In Fig. 216 is shown a group of such craters upon Pa-o-ha

Island in Mono Lake. The lake appears in the upper part of the picture and the craters have been filled with water to a level with its surface. The explosions which opened these interesting craters were not accompanied by any lava, either molten or in solid fragments, the loose rocks lying about them being merely the material blown out of the openings.

Fig. 217.

Crater of Coon Butte, near Canyon Diablo, Arizona.

A similar crater, but of much greater size, is found upon the Colorado Plateau in northern Arizona, and is known as Coon Butte. At some remote time an explosion took place beneath the surface, blowing away the overlying rocks and making an opening three-fourths of a mile across and six hundred feet deep. The rock in which the crater was made is limestone and shaly sandstone. About the rim, which is not more than two hundred feet above the level of the surrounding plain, the rocks have been

bent upward, and huge fragments strew the outer slopes. There is no volcanic material near the butte (Fig. 217).

This crater was first brought to the attention of scientists by the finding of pieces of iron upon its outer slopes by some sheep herders. This iron was thought by those who found it to be fragments of an enormous meteorite which had struck the earth with such force as to bury itself deeply where the crater stands. The

FIG. 218.

Volcanic bombs at the foot of Cinder Cone, Northern California.

iron, indeed, proved to have belonged to a meteorite (Fig. 62), that by mere chance had fallen near the crater and really had nothing to do with it.

If the crater had been made by a body striking the earth, which way would the strata about the crater have been bent?

Cinder and Ash Cones. — Ashes, cinders, scoria, pumice, lapilli, and bombs are the names given to the various products which are blown out of volcanic craters during explosive eruptions. They

vary in size from the dust-like particles of pumice, which may be carried long distances by the wind, to the huge masses of lava known as bombs, sometimes having a weight of several tons (Fig. 218). An eruption may consist largely of mud and solid lava fragments, as illustrated in the case of the eruption of Mt. Pelé in 1902, or it may be merely an explosion of gases giving rise to a crater-like opening in the earth (Fig. 216).

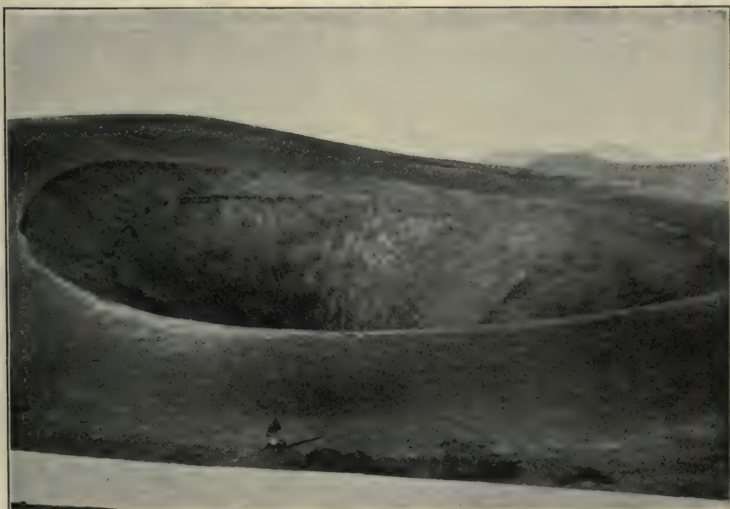


FIG. 219.

The crater of Cinder Cone. The youngest volcano in California.

Some volcanic eruptions consist almost wholly of streams of molten lava. When the temperature of the lava is exceptionally high, the molten material flows away almost like water, so that the points where the lava emerges from the ground are frequently difficult to find.

Cinder cones are built up by the accumulation of the solid or semi-solid fragments falling about the crater. They dot many portions of the volcanic regions of the West, and are in some

cases so recent in origin that the destructive forces have as yet accomplished but little toward the obliteration of their symmetrical features (Fig. 220).

What can you say as to the size of cinder cones compared with volcanic peaks formed of both fragmental and molten materials? What determines the inclination of the walls of the crater and the outer slope of cinder cones? What can you say as to the slope of volcanic mountains built up chiefly of accumulations of molten materials?

FIG. 220.

A symmetrical cinder cone. Owen's Valley, California.

Do cinder cones or mountains of massive lava offer the greater resistance to destruction by erosion? Give reasons for your answer.

The openings in the earth giving rise to simple cinder cones are usually small, and this may partly account for the violence of the explosions; but there is in Nevada, near the sink of the Carson River, a cone which is fully a mile across and has an outer rim which does not rise more than fifty feet above the surface of the surrounding desert (Fig. 316). An interesting thing about this crater is that it is situated many miles from any lava flow.

The craters scattered over the Cordilleran region illustrate the fact that when the molten lava in the throat of a volcano is filled with great quantities of steam and blown violently out, the pumiceous material is carried far over the surrounding country by the wind, and less lofty cones are produced than when the eruptions are not so violent and the ejected material not so fine.

Cinder Cone, near Lassen Peak, California, is remarkable not only for the fact that it is associated with the last flow of lava

FIG. 221.

A portion of the volcanic range known as the Mono Craters. Eastern California.

that has taken place in the United States outside of Alaska, but also for its lofty and symmetrical form. The stubs of the trees that were killed at the time of the eruption of the ashes and the building of the cone are still standing (Fig. 6). The flow of lava after the cessation of the explosive eruptions covered about ten square miles of the surrounding country with a rugged black sheet.

About the base of Cinder Cone are numerous bombs, some of

which are as much as four feet in diameter. They are roundish in shape and must have been hurled from the crater in a partially molten condition (Fig. 218).

The most interesting group of pumice cones and flows of glassy lava in the United States is known as the Mono Craters, and is situated south of Mono Lake in eastern California. The volcanic pile has a length of ten miles and an extreme width of

FIG. 222.

Interior of one of the Mono Craters. The outer rim is formed of volcanic ashes. In the center is a plug of lava.

two miles, and it rises to a height of nearly twenty-five hundred feet above the desert plain (Fig. 221).

The lava streams consisted of viscous material and cooled so rapidly as to form volcanic glass. The explosive eruptions which followed the flows of lava opened craters, some of which are very remarkable. The whole country for many miles about is covered with a thick coating of volcanic ashes.

After the formation of the explosive craters there was in several instances a weak attempt at the expulsion of more molten lava, but the energy below was becoming less active. The lava cooled before filling the crater and formed a solid plug in the throat of the volcano, as is shown in Fig. 222. In Panum Crater, the largest of all the craters, a mass of lava fully one thousand feet across welled up and actually overtopped the crater walls, but it was so thick that it did not run out.

Fig. 223.

A mountain of obsidian lava. One of the Mono Craters.

In connection with what has just been said about explosive eruptions, you should read carefully one of the many descriptions of the eruption of Mt. Pelé upon the island of Martinique, in 1902.

Mountains of Massive Lava. — Mountains formed exclusively by the cooling of lava about the point of eruption are not common. Periods of explosive action usually alternate with those of more quiet outflow; and, besides this, the molten material is usually too thin to build up a mountain of any great height. Fig. 223 shows one of the isolated peaks of the Mono group of craters,

which was made by the outflowing of extremely thick or viscous lava. It has a very different character from the common volcanic peaks.

The Bagdad Crater in the Mohave Desert from a distance has the appearance of being a cinder cone (Fig. 224); but it was in reality made of semi-liquid lava pushed up by an explosive force

Fig. 224.

Bagdad Crater, Mohave Desert, California. In the foreground appears a hillock of scoriaceous lava, where there was a weak attempt of the forces below to form a crater.

from beneath. The crater marks the opening from which once flowed a stream of lava that was very fluid and spread as a thin sheet over many square miles of the desert basin.

The two great volcanoes, Mauna Kea and Mauna Loa, upon the island of Hawaii, although they reach a height of nearly fourteen thousand feet, yet appear to have been formed chiefly by the outpourings of molten lava. The tops of these mountains were

gradually built up by the overflowing of lava from the broad, shallow craters. While most of the material of each eruption ran down the slopes, a little cooled about the craters, and so gradually the mountains grew. Their slopes, instead of having the characteristic cone-shaped profile, are long and gentle. In fact, they reach the ocean on nearly all sides of the island, and during some of the late eruptions the lava flowed over the ocean cliffs.

The Great Volcanic Peaks of the Cordilleras. — The extinct volcanoes of the Cordilleras, which add so much to their scenic attractions, are made in large part of fragmental lava, such as scoria, lapilli, bombs, etc., together with some solid lava. These materials have come from openings in the earth, which have periodically through long ages been the seat of explosive eruptions and quiet flows of lava. The tufaceous lava (name given to the fragmental accumulations) aids in giving the steep slope to the ordinary volcanic peak, although this may be modified more or less by streams of lava.

Are there indications of eruptions ever having taken place in the eastern part of our country? Of what are the Palisades of the Hudson (Fig. 278) formed? What has become of the very ancient volcanoes of the earth's surface, and how can we sometimes determine their former location?

Mention a number of the loftiest peaks in Mexico and South America, and state of what they are formed. Find out what you can about the highest peaks of Alaska, and of the recent volcanic eruptions of the Aleutian Islands.[1]

Reaching the whole length of the Cascade Range, from Northern California through Oregon and Washington, is a line of lofty volcanoes which are all now extinct. These range in height from ten thousand to nearly fourteen thousand five hundred feet. Their slopes are steep and rugged and their summits more or less snow-covered throughout the year. Altogether they present a most grand and inspiring spectacle (Figs. 2 and 366).

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[1] For a full description of volcanoes, consult *Volcanoes of North America*, by I. C. Russell.

Excepting the San Francisco Peaks in northern Arizona (Fig. 225), there are no other volcanic mountains in the United States approaching them in size.

The most important peaks of the Cascades are Lassen and Shasta in California; Pitt, Three Sisters, Jefferson, and Hood in Oregon; Adams, Baker, Rainier, and St. Helen's in Washington. There was formerly another lofty volcano between Mt. Pitt and the Three Sisters, but this, during a period of activity, had its foundations melted and fell in. It is now represented by the depression in which Crater Lake lies (Fig. 226). This mountain is thought to have been nearly the size of Shasta, and has been called Mazama.

Fig. 225.

San Francisco Peaks, northern Arizona.

Mt. Shasta might be taken as a type of these volcanoes (Fig. 2). It is built upon a broad foundation about seventeen miles in diameter. The slopes, beginning gently at the bottom,

gradually increase in angle and ruggedness until near the top, the summit having an elevation of 14,380 feet.

The mountain has been of slow growth and its history has been checkered. Upon the northwest slope is Shastina, an older and more eroded crater. The most recent eruptions have occurred near the base. From one of these smaller craters a stream of lava flowed down the canyon of the Sacramento River a distance

FIG. 226.

Crater Lake, Oregon. At the right are cliffs nearly 2000 feet high. The small island is known as the "Phantom Ship."

of fifty miles. The mountain now seems to be extinct; and, since the last eruption from its summit, it has been greatly eroded by water and glaciers. Owing to the large proportion of tufaceous lava entering into the composition of Shasta it is very easily worn away.

We can picture in our minds the scenes at the commencement of this great mountain and during its long period of building.

First there was nothing more than a cinder cone, like hundreds of others which now lie scattered over the region, but its crater had a wider and deeper connection with subterranean forces. Through long ages, periods of quiet alternated with those of the flowing out of fiery streams of lava and explosive eruptions. The finer particles spread over miles of the surrounding country, but the coarser, together with portions of the cooling lavas, accumulated about the crater. The result was at last a mighty mountain, which became so lofty that the eruptive forces found easier vent upon its sides. The lava cooled in the throat of the volcano and its work was done. Now the only remaining sign of activity is a hot sulphur spring near the summit.

Study carefully the Shasta special sheet.

Laccolitic Mountains. — Laccolitic mountains and volcanic necks form another illustration of the fact that the features of the earth's surface are the product of two opposite forces, one building up and the other tearing down. Such mountains are really mountains of erosion as they stand to-day, although they owe their existence in the first place to masses of molten matter which have been squeezed upward into surface rocks.

The laccolitic mountain type is particularly characteristic of those portions of the Rocky Mountain and plateau region in which the rock layers are in general but little disturbed. Try to picture in your mind the effect of enormous masses of molten rock which are being pushed upward from some point deep within the earth. The adjoining rocks will be broken and partly melted, but cannot be shoved aside, because of the enormous weight upon them. Nearer the surface, where there is not so much weight to hold them down, the rocks, if they are flat or nearly so, will begin to yield and slowly rise until they become arched in dome-like mountains. Then the igneous masses, instead of breaking through the surface, spread out underneath these domes in enormous lens-shaped bodies. This interesting

FIG. 227.

The Devil's Tower (Mato Tepee), Wyoming.

mountain type was first described by Gilbert, from the Henry Mountains in southern Utah. Here the stratified rocks, which originally arched over the mountains, have been worn away by erosion, exposing the once molten rock beneath. Dome-like elevations occur in other parts of the plateau region, and some of them have undergone so little erosion that the arching strata still hide the igneous masses which formed them.

FIG. 228.

Indian shell heap on the Damariscotta River, Maine. Illustrative of artificial elevations.

Prepare a sketch, showing a dome of arching rocks with a lens-shaped body of igneous rock below and a connecting channel leading downward into the interior of the earth. Prepare another sketch, showing what you think would happen if a molten mass were forced upward into vertical rocks. Would a laccolitic mountain be formed in the latter case?

In northeastern Wyoming there is a most remarkable tower-like rock known as the Devil's Tower, or, in the Indian language, Mato Tepee, meaning "bear lodge." The rock rises with almost vertical walls to a height of over five hundred feet from the

summit of the hill upon which it stands. Its origin has given rise to much discussion, earlier opinion favoring the view of a volcanic neck, while later studies have led to the conclusion that it is a remnant of a laccolitic sheet, the core of which is represented by the Little Missouri Buttes a few miles to the west. It is believed that when the intrusion took place, the lens-shaped

FIG. 229.

An army of sand dunes moving eastward. Colorado Desert.

igneous body, of which Mato Tepee is a small remnant, was four thousand feet below the surface. Erosion has removed this thick mass of overlying stratified rock, and all but a small portion of the igneous body (Fig. 227).

How could it be demonstrated whether this is a remnant of a laccolitic sheet or a volcanic neck?

The wonderfully perfect columnar structure has given to the tower its precipitous sides, since the rock weathers and breaks

down most easily along the seams separating the columns. The fact that the columns are practically vertical is another reason for believing the tower to be a remnant of a horizontal sheet of igneous rock, because in cooling lava the columns form at right angles to the surface of the sheet.

The rock of Mato Tepee is very resistant, and in its isolation is not subject to erosion, being affected merely by disintegration

Fig. 230.

A sand dune moving inland and burying forest trees. Coast of Northern California.

and the down-pulling force of gravity. In the course of time, however, the erosion of the soft sedimentary beds underneath will bring about the downfall of this majestic tower.

Volcanic Necks. — The solidified lava in the throat of an extinct volcano is much more resistant to erosion than the main body of the mountain; so that when the latter has finally been worn down, its central core of lava will long remain as a pictur-

esque feature of the landscape (Fig. 214). Many other igneous masses, which have been squeezed into the sedimentary rocks, when exposed to erosion wear away very slowly. Hence in a worn-down mountain region the localities of the eruption of igneous rocks are marked by more or less prominent peaks.

In the central Coast Ranges of California there is a line of rugged peaks known as the San Luis Buttes, which may be con-

FIG. 231.

Marginal glacial moraine. Sierra Nevada Mountains.

sidered as typical volcanic necks exposed through the erosion of the softer rocks around them. The most northern one of the series, known as Morro Rock, stands out in the ocean as a precipitous knob of bare rock rising to a height of nearly six hundred feet. This is the grandest object upon either coast of the continent, and from its very resistant character bids fair long to withstand the destructive agents (Fig. 352).

MISCELLANEOUS ELEVATIONS.

Sand Dunes. — Hills of sand, or *dunes* as they are properly called, abound upon low and sandy coasts. They occur also in certain portions of the desert regions of the earth where there are strong winds. Upon the Colorado Desert there is a large area of mountainous dunes, like an army in number, slowly moving eastward and burying the scanty vegetation (Fig. 229).

FIG. 232.

A terminal glacial moraine above Lake McDonald, Montana.

Is their formation favored most by the winds which blow on or off shore? Give reasons for your answer. If you have access to sand dunes, study their formation and the way in which they move inland. If there are no dunes near by, you can learn something of their general character by a study of snowdrifts.

What can you say as to the size of the grains in sand dunes? Of what are the grains composed in most cases? Describe some of the means used to stop dunes moving in upon cultivated fields and buildings (Fig. 230). What is the only effective method?

Tell from the shape of the dunes in Fig. 229 whether they are moving to the left or to the right.

In southeastern New Mexico there is a broad desert valley partly covered with dunes of an unusual kind. They are known as the "white sands," and are formed of gypsum. Granular gypsum abounds in the beds of dry lakes in the vicinity, and this the wind has piled in these remarkable hills of sand.

Explain what you think might be the origin of the gypsum sand. What is the origin of the quartz sand of ordinary dunes?

FIG. 233.

Kettle hole and kames, near Jackson Lake, Wyoming.

Glacial Accumulations. — The rock material which glaciers tear from the surfaces over which they pass, as well as that which falls upon them from the rock slopes above, is borne along and finally dropped either upon their margins or at their lower ends. These rock fragments are deposited without any order, big and little fragments being mixed confusedly together (Fig. 84). Such deposits are sometimes of vast extent and great thickness, changing in an important manner the preëxisting surface features.

The rock waste which collects along the margin of a glacier is known as a *marginal moraine* (Fig. 231). That which is heaped up at the end is a *terminal moraine* (Fig. 232). The ice in this last illustration is so covered with rock fragments that it is almost hidden.

Interesting geographic features appeared when the great ice sheet retreated from the northern United States. Islands of ice

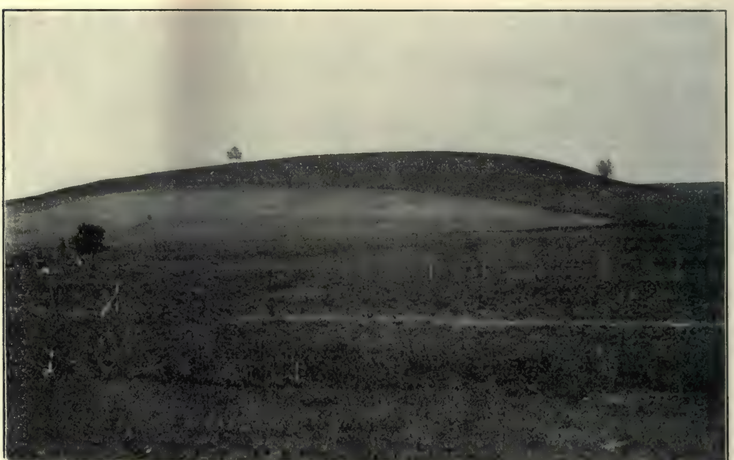

FIG. 234.
Drumlin, south of Newark, New York.

sometimes remained for a time behind the main body, while currents of water laden with débris flowed about them. When these patches of ice melted, they left depressions which are now often occupied by lakes. To small, basin-shaped depressions of this kind we give the name of *kettle holes.* Gravel ridges formed under the ice by streams of water are known as *eskers ;* and irregular hummocky hills of gravel built up about the margin of the ice sheet are termed *kames* (Fig. 233). Hills in the region of the glacial till having a low oval shape are called *drumlins* (Fig. 234).

Huge masses of rock are sometimes dropped in peculiar positions by the melting glaciers (Fig. 259). Many of the glacial valleys in the high mountains of the West are dotted with boulders, as if giants had been at play upon the smooth rock surfaces.

The study of glacial features is especially important for those living in the Northern and Eastern States. If your home is in this region, you should, with the aid of your teacher or of a supplementary book, take up in more detail the work of the ice which once covered the country.

Spring Deposits. — The most important spring deposits of the United States are found in the Yellowstone Park, about the hot springs and geysers. The mammoth hot spring terraces show in particular what a great quantity of lime is carried in solution by the water (Fig. 143). Judging from the manner in which it incloses tree trunks, the deposition must be quite rapid.

In some mineral-bearing regions, the veins of quartz which are formed from former springs weather out quite prominently because of their great resistance. Along the Mother Lode in California are many prominent outcrops of the great quartz veins (Fig. 64).

CHAPTER XIII.

THE INFLUENCE AND IMPORTANCE OF MOUNTAINS.

Climate. — Next to latitude, elevation is perhaps the most important factor in determining the climate of a place. In fact, without leaving the home latitude, one may, by ascending a high mountain, experience all the climatic changes which one would find in going to the polar regions. Upon the California coast, during a portion of the year, there is an interesting exception to the general rule that the cold increases with elevation. In the summer the lowlands in the vicinity of San Francisco are buried beneath a blanket of cold fog; while upon Mt. Tamalpais, two thousand feet above, a normal summer climate is enjoyed.

Mention the factors, previously referred to, which together make up the climate of a place. What would you expect the climate of your home to be, judging merely from its latitude? How does its real climate differ from this? Is the difference the result of elevation, of nearness to some large body of water, or of direction of the prevailing wind?

Observe the behavior of clouds about hill and mountain tops as a storm comes up and passes away. Where do the clouds hang longest? What reason have you for thinking that it rains and snows more upon mountains than in adjoining valleys? If the Appalachians should be elevated several thousand feet, in what ways would the climate of the region be affected? What conditions might lead to another extension of the glaciers from the north down into the United States?

Contrast the average temperature of highlands with valleys at different seasons of the year. Where does the frost first come in the fall? So far as frost is concerned, why is it better to plant orchards upon a hillside, rather than in the bottom of a valley?

The presence of cool mountain tops, by aiding in the condensation of moisture, often renders regions habitable which would

Corrected to December, 1897

FIG. 235.

LIFE ZONES OF THE UNITED STATES
BY
C. HART MERRIAM.

otherwise be arid wastes. In the deserts of the West luxuriant crops are grown by irrigation, the water being supplied by the streams of the nearest mountains.

The position of mountain axes with reference to the movements of the prevailing storms has an extremely important effect upon the climate of our country. Vast areas in the western

Fig. 236.

Orange groves at the base of snow-clad mountains. Looking north from Redlands toward the San Bernardino Range, California.

portion are deficient in rainfall because of the mountain barriers that extend across the path of the storms.

If the important mountain systems, such as the Coast Ranges, Cascades, and Sierra Nevadas, were replaced by others having an east and west direction, a large part of the plateau region would be well watered. As it is, there exists the most remarkable contrast in climate on opposite sides of the mountain ranges near the Pacific Ocean. The storms come off the ocean, passing in an easterly direction, so that the western slope of the Sierra

Nevada Range receives a heavy precipitation and is densely forested, while the eastern side partakes of the desert character of the Great Basin.

So completely is the moisture taken from the air by the Sierra Nevada Mountains, rising twelve thousand to fourteen thousand feet above the ocean, that the next range to the eastward, the Inyo-White Mountain Range, although in places almost as high, receives but a small precipitation.

Fig. 237.
The digger pine.

A similar contrast appears upon opposite sides of the Cascade Range, but the Columbia Plateau lying to the eastward is not so arid as the Great Basin. This is because the Cascade Range is not so high as the Sierra Nevada, and the storms are more frequent.

Have the Appalachian Highlands bordering the Atlantic any effect upon the climate of the interior of the continent? Why are the climatic conditions upon their eastern and western slopes so nearly the same, while upon opposite sides of the Sierra Nevada and Cascade systems there is such a contrast?

Climate and Life. — The influence which great elevations exert upon climate, and through this upon all forms of life, is of the utmost importance to us. The growth of vegetation is most intimately related to moisture and temperature, and over extensive

regions of the earth the latter are influenced to a marked degree by the presence or absence of mountains. A rank vegetation will develop in a warm and moist region, even though the soil is of the very poorest; while either too great cold or too little moisture makes such a growth impossible.

The climatic zones of the globe are really life zones, and each is characterized by certain plants and animals. The boundaries

FIG. 238.
The manzanita bush.

of these zones depart very widely from the parallels of latitude, being determined by a number of factors (Fig. 235).

If you trace the isotherms upon a weather map, you will discover what an important effect elevation has in determining their courses.

The influence of elevation can be seen when the mountains are no more than one thousand feet high; and in the case of the lofty mountains of the West the great change in climate and life between their bases and summits is extremely interesting. In Southern California one may live among perpetually blooming

flowers and look up to lofty mountain peaks, only a few miles away, which have a semi-arctic climate (Fig. 236).

FIG. 239.

In the yellow pine forest.

Forest trees would be absent from a large portion of the western United States if it were not for the presence of mountains. Coniferous trees, such as the fir, require a certain amount of rainfall and a cool or temperate climate. In the northwestern

part of our country these trees are found growing down close to the ocean shore; but as we go south through the Cordilleran region, where the rainfall is less and the heat greater, the lower limit of these trees rises higher and higher, until in northern Arizona it reaches an elevation of seven thousand feet (Fig. 244).

The upper limit of forest trees is determined by cold, and is known as the *timber line.* The lower limit of forests, determined chiefly by moisture, is equally well marked and has been called the *dry timber line.* In fact, so uniform is the dry timber line over large portions of the desert regions, that one can tell the elevation very closely when one has reached the downward limit of tree growth (Fig. 244).

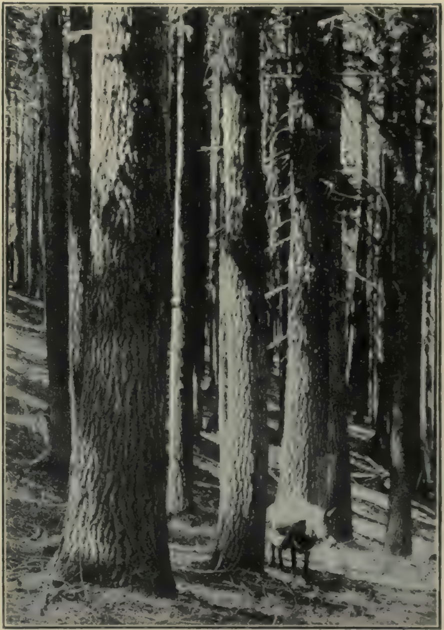

FIG. 240.
The white fir forest of the Upper Transition zone.

The ascent of one of the high mountain ranges in the West offers an excellent opportunity to note the effect of elevation upon climate and life. We will choose the Sierra Nevada Range and ascend it from the semi-tropical lowlands of the Great Valley of California to the timber line.

Leaving the Great Valley with its grassy, prairie-like surface, which in some places bears groves of oak trees, we begin to climb the foothills. The climate and vegetation of the valley is that of

the Lower Sonoran zone; but in the foothills the Upper Sonoran is reached (Fig. 235). Here the slopes are thickly dotted with oaks, and among them the lowest growing of the conifers, known as the digger pine (Fig. 237). The steeper hills are in many places densely covered with low shrubs, known in general terms as chaparral. One of the most important of these shrubs is the manzanita (Fig. 238).

Continuing upward, we enter the mountains proper, and at elevations of twenty-five hundred to four thousand feet find ourselves in the yellow pine forests of the Transition zone (Fig. 239). We must not think of the different zones as set off by any sharp bounds, for the trees of one zone extend into the adjoining zone, gradually being replaced by those of the new zone. Each zone has, however, certain species which reach in it their greatest development.

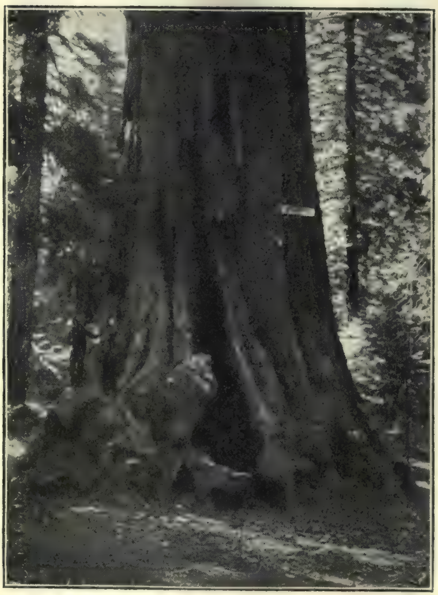

Fig. 241.
The Sequoia gigantea.

As we pass the level at which the yellow pine is most abundant, other large conifers begin to appear, among which are the sugar pine, incense cedar, Douglas spruce, and white fir (Fig. 240). In this dense forest, at an elevation ranging from five thousand to seven thousand feet, we come upon the *Sequoia gigantea* (Fig. 241). We are now in what is known as the Upper Transition zone. Here

the conditions are particularly favorable for the growth of conifers. The trees are large and stand close together, so as almost to shut out the sunlight.

As we continue the ascent, the characteristic trees of this zone begin to disappear and others, such as the tamarack on the moist lands about the high meadows and the red fir upon the drier slopes, take their places. The forests are still dense in places, but

FIG. 242.

Foxtail pine, near timber line, Sierra Nevada Mountains. In the distance is Harrison Pass, with an elevation of 11,500 feet.

the trees are not as large as those lower down. The rocky areas begin to crowd them out, so that as you look down from some peak the somber green is not dense or continuous. The tamarack pine, red fir, and alpine hemlock of this altitude belong to the Canadian zone.

Now the effect of the cold air, the short summer, and the winter storms begins to be seen, and we enter upon the Hudsonian

zone, the typical trees of which are the mountain white pine and the foxtail pine (Fig. 242). Toward their upper limits these trees become low and dwarfed, branching close to the ground; and at the extreme limit of timber growth, where the elevation is about eleven thousand feet, they rise scarcely more than five feet from the ground and are gnarled and knotted (Fig. 243).

Fig. 243.

Dwarf white pine at timber line, Sierra Nevada Mountains.

The cold climate of these mountain tops does not permit the growth of trees farther upward; but throughout much of the upper or Alpine zone the rocky slopes support, in favored spots, low arctic shrubs and lichens, and during the short summer a few bright flowers may be seen.

The animals are also distributed in zones, each of which has its permanent characteristic species, although there are some species which migrate with the changing seasons.

The San Francisco Peaks in northern Arizona, rising from the Colorado Plateau to a height of 12,800 feet, exhibit an interesting series of life zones, from that of the desert at their base to the Alpine zone at the top (Fig. 244).

Compare the distribution of the life zones of the United States (Fig. 235) with a chart of the mean annual isotherms and explain the similarity exhibited. In which zone is your home? What are its most characteristic native plants and animals?

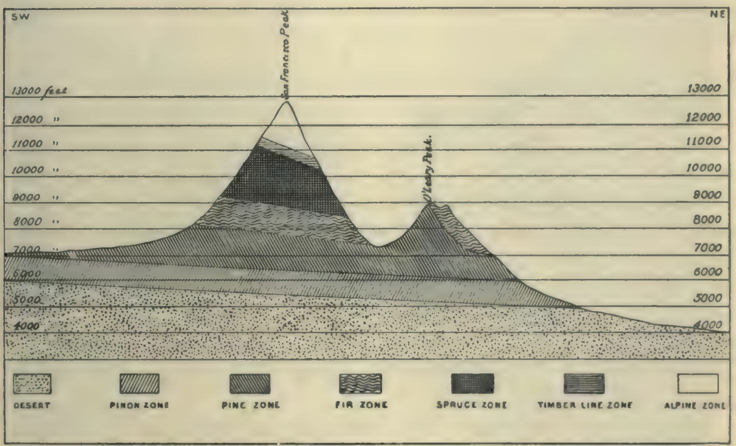

FIG. 244.

Section of life zones of San Francisco and O'Leary Peaks, Arizona. Note the depressions of the zones upon the north sides.
(After C. Hart Merriam.)

Explain, from any observations which you are able to make upon hill slopes in your vicinity, why it is that the life zones are lower upon the north than upon the south sides of mountains.

Study carefully the distribution of the native trees about your home, for the purpose of finding out the relation which they bear to the soil, moisture, and temperature. If mountains are accessible, note the difference in the vegetation between their tops and bottoms, and determine how much this is a product of elevation and how much of soil and moisture.

Barriers to the Distribution of Life. — Explain as fully as you can all the different ways in which a lofty mountain range may act as a barrier to the spread of living things from one part of a country to another. Which is the more important barrier, steep slopes and precipitous rocks, or climate? How is the spread of birds, animals, and plants relatively affected by mountain barriers?

The contrast of climatic conditions between the south and the north slopes of a mountain is more than equaled by the contrast between opposite sides of a mountain range extending across the course of the prevailing storms. This is illustrated by the Sierra Nevada Mountains, which upon the west are heavily forested nearly to their base, while upon the east side, the lower we go the more barren the slopes become.

If you will study a relief map of the region about San Francisco Peak, Arizona, you will see that it is separated by hundreds of miles of warm and desert-like plateaus from any mountain chain extending toward the north. How would you explain the presence of Alpine plants upon the higher slopes of San Francisco Peak? Many other isolated mountains in the temperate and sub-tropic zones are characterized by plant and animal life which could not reach them under the present climatic conditions. Might the climate existing during the Glacial period have had something to do with creating the present anomalous distribution?

In what different ways may the seeds of plants be mechanically carried across mountain barriers? Mention some plants the seeds of which are especially fitted to be borne by the wind to long distances. Are plants or animals the more easily restrained by mountain barriers? Give reasons for your answer.

How would you account for the presence of fish in a mountain stream that sinks in the earth before connecting with a lake or ocean?

Influence upon People. — The study of history shows how very greatly our ancestors were influenced by the presence of mountain ranges. Once mankind was shut in by such barriers almost as completely as were the lower animals. Mountains have made communication between different tribes and nations so difficult that each has gone on living its own life, often almost entirely ignorant of its neighbor on the other side of the barrier.

The Indians of the Pacific slope are divided into almost as many tribes as there are valleys occupied by them, and each tribe speaks a different dialect or language.

What can you say as to the effect of the Appalachian barrier upon the westward spread of the early settlers of the Atlantic coast? Where are the passes through which the emigrants pressed toward the Ohio Valley? What do you think would have been the effect upon the settlement of the

FIG. 245.

Wagon road over the San Fernando Pass, Southern California.

continent if a mountain range like the Sierra Nevada had been found stretching along the Atlantic coast? What is thought to be the effect of mountain barriers upon the growth of dialects and languages?

The discovery and settlement of our country has been very greatly influenced by the existence of lofty and rugged mountain ranges. It frequently happens that there are low gaps or passes through these, making it possible to cross them by horse trail or even by wagon road and railroad. The easiest routes across the mountains were known to the Indians long before the whites

came, and undoubtedly many of these trails were used by wild animals before the time of the Indians.

Where the divides are sharp, the difficulty of constructing a wagon road over them is an important factor in the relations existing between two adjoining settlements (Fig. 245). If a divide is rounded, even though it is several thousand feet high,

FIG. 246.
Soledad Pass, leading from the Great Basin (Mohave Desert) to the Pacific drainage, Southern California.

a railroad may cross it without difficulty, by winding around the mountains until the desired elevation is gained (Fig. 246).

Explain why it is that a pass is more likely to occur in a mountain range where two important streams head opposite each other. Study carefully the gaps in the hills or mountains near your home with reference to this point. Also notice if the wagon roads take advantage of such gaps.

Rivers frequently give rise to passes of great importance through mountain ranges. An example of this is presented by

FIG. 247.

To face p. 301

the Columbia River and the Cascade Range (Fig. 299). Other passes, like the "water gaps" of the rivers flowing from the Appalachian Highlands to the Atlantic, offer easy access to the very heart of an upland region otherwise difficult to gain (Fig. 248). The Royal Gorge of the Arkansas in Colorado is perhaps the very best example which we have of a mountain

FIG. 248.
Delaware water gap.

barrier cut through by water, thus permitting a railroad to gain the summit valleys of the Rocky Mountains with little difficulty (Fig. 291).

Before the geography of the Cordilleran region was known, the Rocky Mountains were supposed to form an insurmountable barrier to the expansion of our country westward; and if it had not been for the gaps or passes, the United States might have been limited by these mountains.

For a long time California was reached only by way of the Pacific. In fact, it was more than two centuries and a half after

its discovery before the first party (the Lewis and Clark Expedition, 1805) crossed the continent and reached the ocean at the mouth of the Columbia. Few other regions of the world were ever more isolated by rugged mountains and broad deserts.

The important part played by mountain barriers is illustrated by the early history of the Great Basin region. Frémont and his party, ignorant of the mighty wall of the Sierra Nevada, came near perishing upon its snowy crest through the vain attempt to find, and follow down to San Francisco Bay, a river which was supposed to rise in the Rocky Mountains and flow westward across the course of this lofty range of mountains. The same mountains, so cold and snowy in winter, caused the terrible suffering and death of many of the Donner party. To the south, Death Valley was the scene of the breaking up of another party of emigrants and the death of many, because of lack of water and food and the presence of barrier after barrier of mountains stretching across their course.

Many mountain barriers were almost impassable to man so long as he remained in a savage condition, for then he had little more power over nature than have the lower animals. Now we can do almost anything we please with the obstacles in our path. The Great Northern Railroad, instead of winding with steep and dangerous grades over the Cascade Range, tunneled through the mountains. It has even been proposed to tunnel through the Sierra Nevada Mountains below Donner Pass, where steep grades and winter storms offer obstacles to communication between the East and the West.[1]

RESOURCES OF MOUNTAINS.

Agriculture and Stock Raising. — In proportion as the slopes become steep and rocky, they are less adapted to agriculture; but unless heavily timbered or extremely rocky, they will support

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[1] The most noted tunnel ever constructed is the Simplon. It leads through the Alps from Switzerland to Italy, and has a length of twelve miles.

large numbers of cattle, horses, and sheep. Owing to the heavy rainfall and the lateness of the spring, mountains furnish green meadows while the lowlands are drying up under the summer sun.

Rolling lands and foothill regions are often better adapted to many kinds of agricultural products than the lowlands along the streams. Under what conditions would the reverse be true? Fruit growing is particularly favored by the soil and climatic conditions of foothill lands.

Mention some of the products which are most hardy and can be grown highest upon mountain slopes. What are the characteristics of New England as an agricultural region? Is it best adapted to agriculture, mining, or manufacturing? Give reasons for your answer. The mountains of the West often rise from a lofty, plateau-like surface. What effect has this upon the possibilities of agriculture in the valleys scattered through them?

Grass will grow far above the limits of other products, for it will stand frosty nights. Very high mountain valleys are, therefore, suitable only for pastures, no matter how good their soil may be.

Lumbering. — Although the distribution of forest trees is determined largely by climatic conditions, yet soil is concerned to some extent, as is shown by the growth of pine, to the exclusion of most other trees, upon the sandy reaches of the South Atlantic coastal plain, in portions of Michigan, and in other places.

A certain amount of rainfall is, in our latitude, the first requisite for forest growth; and rainfall is often intimately related to elevation. In the eastern States the rainfall is everywhere sufficient, upon the lowlands as well as the highlands, and the effect of elevation upon the forests is here not very evident. Upon the northwest coast the rainfall is also heavy, being in places as much as eighty inches a year; and here the forests creep down to the very edge of the ocean. In many portions of the West, however, forests are not found below a certain elevation, because of the lack of moisture.

In the arid region, the presence of lofty mountains rising above the semi-arid plateaus is of the highest importance for the existence of both water and forests. If you could compare the annual precipitation in the valleys with that upon the mountains adjoining, you would readily understand that this whole country would be uninhabitable without the mountains.

Water Supply: Water Power. — The uplands and mountain divides are important, because here the streams take their rise. The more slowly the water of the winter storms runs away, the more there will remain for summer use.

In what manner is the winter precipitation held back by high mountains so as to afford a summer water supply in the valleys? How is the temperature concerned in this problem? What has been the result, upon the summer water flow, of cutting the forests upon mountain slopes? Has this affected the streams in your locality? Has the removal of the forests anything to do with the destructive spring floods in the Ohio Valley? Explain fully the effect of removing vegetation from steep slopes.

What plan is the general government now employing to preserve the forests about the heads of the streams?

Where the streams from the Appalachian highlands, flowing down over hard rocks, encounter the soft sedimentary strata of the coastal plain, there are rapids and waterfalls, which have determined the location of a line of cities. Here the power which running water affords for mills and manufacturing establishments has long been utilized.

Mention the leading cities situated upon the "fall line." Describe in detail several of the causes which made these spots so favorable for settlements.

Find out what you can about the general geographic features of the region around Niagara Falls, the Falls of St. Anthony, and the Great Falls of the Missouri River. What conditions have led to the formation of the waterfalls mentioned?

Why is it that over the glaciated portion of the United States, even where the relief is not great, waterfalls and rapids are numerous?

Important waterfalls are occasionally found in regions of low relief, but usually the most water power is to be obtained in mountainous districts.

What are the drawbacks to placing mills near waterfalls when the latter occur in mountainous regions? In what manner has the power frequently been carried from the mountain canyon to some convenient and accessible spot upon the borders of the open country? What is the chief means employed for the transmission of power at the present time, and how far is it sometimes carried? Is the location of cities close to water power as necessary now as it once was?

Mining. — Mountainous regions have long been the seat of important mining industries. The steep, rocky slopes and deep canyons make the discovery of mineral veins much easier than in a more level country. The Colorado River has cut a trench a mile deep through the undisturbed sedimentary rocks and exposed minerals of which the surface gives no indications.

Review what you have already learned about the distribution of minerals and explain why the metallic minerals are usually found in mountainous countries.

Explain by sketches the conditions in the Appalachian region which make mining there easier than in the Ohio Valley. Give your reasons for the absence of important deposits of the precious metals in the eastern United States. What are the most important mineral products of this region?

The mountains of the West, we have already seen, are extremely important because of their timber and water supplies. They are also particularly noted for their deposits of gold, silver, copper, quicksilver, and zinc. Except in a few places, coal is not an abundant mineral.

Describe the geographic conditions necessary for the formation of coal beds.

Why it is that gold occurs in some parts of the Cordilleran region, while lead, zinc, silver, and copper particularly distinguish other parts, we do not know. We are certain, however, that fissuring of the crust, the heat of molten rocks, and the circulation of

mineral-bearing waters are the first requisites for the formation of mineral-bearing veins.

The western slope of the Sierra Nevada Mountains is noted for its gold belt. Here is the Mother Lode, an important series of gold-bearing veins having a length of more than one hundred miles. In many regions silver, gold, and copper occur together, while others are noted for silver, lead, and zinc.

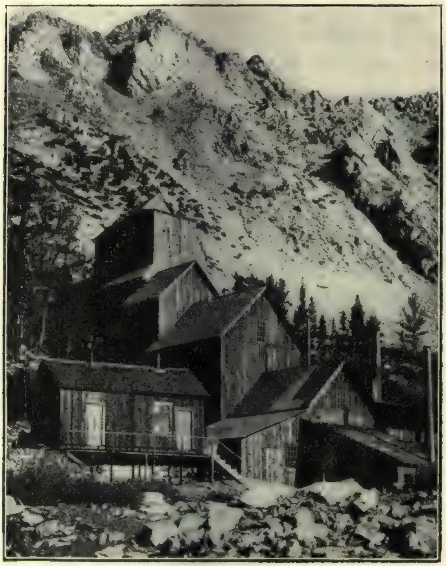

FIG. 249.

May Lundy Mine. Situated in the Sierra Nevada Mountains, two miles above the sea.

Gold was the first of the important minerals to be found and mined in the West. Its discovery has had a greater influence than anything else upon the rapid settlement of this region. Gold is usually found native or in more simple combinations than silver. After the excitement about gold, came the period of silver mining, which marked the history of Nevada and Colorado particularly. When silver became too cheap to pay for mining in many places, it was discovered that there were in these States enormous deposits of low-grade gold ores which had been overlooked. Colorado, once producing so much silver, became, in 1897, the leading gold-mining state.

The conditions under which gold mining is carried on in the rugged mountains may be illustrated by the May Lundy Mine upon the eastern slope of the Sierra Nevada Mountains. The

mill stands in the foreground near the bottom of a steep-walled canyon (Fig. 249). The mine is nearly two thousand feet higher up on the mountain side, and here the miners live at an elevation of ten thousand feet, their cabins being just visible in the picture. This mine is opened most conveniently by tunnels. The mountain in the background rises nearly two thousand feet above the mine and is seamed in every direction with veins of gold-bearing quartz. The ore is run down to the mill by a wire cable, and provisions are carried back by the same means. The use of the cable makes it possible for mining to be carried on during the winter, when the snow lies many feet deep.

Mining in mountainous regions is much facilitated by the presence of forests and water power. A large mine requires an enormous amount of timber for the support of the roof of the workings. Water power applied to the running of mills, either directly through its pressure or indirectly through its conversion into electric energy, so cheapens mining that many deposits of ores can be worked which otherwise would not pay.

Describe the advantages and disadvantages of any hills or mountains in your vicinity. Discuss their effects upon climate, productions, water supply, industries, lines of travel, and commerce. Prepare a sketch map, showing the relation between the physical features and the railroads, wagon roads, and trails.

Describe the natural resources of the region in which you live and the dependence of these upon the geographic features. Are there any peculiarities of climate which you can trace to the geographic features?

By what means and along what routes did the first settlers reach the locality in which you live? What geographic conditions favored them? What opposed them?

What are the climatic advantages and disadvantages? In what manner do the geographic features influence the occupations of the people? Are there any manufacturing establishments near? What particular advantages have their locations?

Make a list of the chief agricultural, fruit, and mineral products of your region and the conditions which favor the growth of each of these industries.

Recreation Grounds. — The picturesque mountains of the United States, wherever they are accessible, are becoming summer pleasure grounds. The unnatural conditions of life indoors are being ameliorated as far as possible during the summer, both because of the demands of health and because of a growing love for the wild, free life of the mountains.

Mountains, then, as promoting a love of nature and furnishing recreation and opportunities for healthful outdoor life, have an importance which cannot be overestimated. Parks have been formed in various parts of the country in an effort to preserve as much as possible of mountainous tracts in their primitive wildness and beauty.

CHAPTER XIV.

VALLEYS AND CANYONS.

Introduction. — The earth's surface is the product of the struggle between two forces. The one within builds volcanoes and pushes up great blocks of the crust. The one without sculptures hills and mountain peaks out of the uplifted crust. The force within not only pushes up the surface to make mountains, but bends it down between the mountain ridges, giving rise to depressions. These we call *structural* basins and valleys, to distinguish them from the depressions which are formed during the sculpturing of a mountain range. We find, then, valleys produced by the downfolding of the earth's crust, and valleys produced by erosion.

What is the origin of canyons? Distinguish between a valley and a canyon. From a study of the geographic features in your vicinity, describe the growth of a valley through the process of erosion. Review the description of the Virgin River (p. 137). What is the origin of the valley in which you live?

Valleys formed by Running Water. — The agent everywhere at work, either making valleys or shaping those formed by other means, is running water. In the eastern part of our country the valleys are the product of erosion, but in the West the more important ones have a different origin.

With the aid of the Harper's Ferry, Virginia, and the Hummelstown, Pennsylvania, sheets, explain the adjustment of the smaller streams to the structure of the rocks and the development of the important longitudinal valleys. This is a region of folded rocks. Do the longitudinal valleys occupy axes of downfolding of the crust or have they appeared as the product of erosion in rocks differing in resistance?

No definite line can be drawn between a canyon and a valley. When, however, a stream has widened out its channel so as to possess bordering lowlands and a flood plain, the name of *valley* may be applied to the excavation which it has made, even though the walls should still retain their canyon character. The far-famed Yosemite Valley is an example of the local widening of a

FIG. 250.

Looking up the Yosemite Valley. El Capitan upon the left; Bridal Veil Falls upon the right.

canyon, which in general is quite similar to a number of canyons on the western slope of the Sierra Nevada Mountains. The valley has a width of three-fourths of a mile, a length of eight miles, and is inclosed by almost vertical walls having an average height of about three thousand feet. The presence of a valley here, with precipitous walls, is the result of the fact that the granite is intersected by vertical joints. As running water and

p. 311

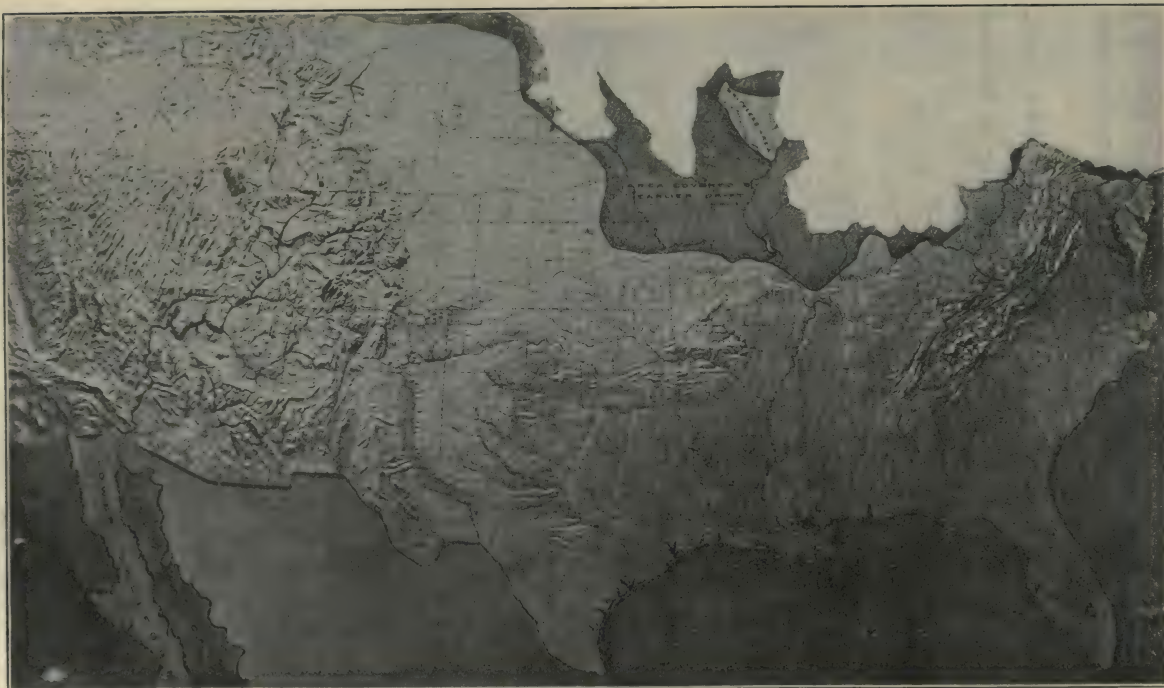

Fig. 251.

Relief map of the United States : showing the extent of the glacial ice cap.

(Copyright by Howell, Washington, D.C.)

glacial ice widened what was once a canyon, the granite broke down along these lines of weakness (Fig. 250).

Consult the Yosemite, California, and Mt. Marcy, New York, sheets.

What Glaciers have had to do with the Making of Canyons and Valleys. — The extent of the ice sheet over the northern United States (Fig. 251) is in most places clearly marked by the peculiar geographic features which it left. We have already

FIG. 252.

Lambert's Dome, Sierra Nevada Mountains. A dome of granite in the path of the great Tuolumne glacier.

learned something of the deposits formed by the ice. Now we want to find out what we can about the erosive power of ice when moving over the land.

When the great glaciers swept southward into the United States, they scraped off the soil, tore away the disintegrated rock, and bore the débris along with them. They rounded and polished the bed rock wherever it was resistant, but where it

was soft they dug into it sufficiently to produce valley-like depressions. The basins occupied by the Great Lakes are believed to have been deepened in this manner during the Glacial period.

In the western portion of the United States there was no continuous ice sheet, although this condition was nearly approached in the extreme northwest. The northern Rockies and Cascades were practically buried beneath the ice, and broad glaciers moved

Fig. 253.

Roches moutonnées, Sierra Nevada Mountains.

down to the lowlands bordering them. At that time the land stood higher than it does now, and large ice sheets spread westward over the Puget Sound region to Vancouver Island and down the present fiords to the east and north of the island.

As one follows the Cordilleran region southward, signs of glaciation become less distinct, and a few miles south of Mt. Whitney they disappear entirely. In the region of the Yosemite

Valley the glaciers did not descend below an elevation of about three thousand feet; while near Mt. Whitney their lower limit was some six thousand feet.

Two factors brought about the rapid shrinking of the glaciated area toward the south; one was increase of temperature, and the other, decrease in precipitation.

FIG. 254.

A hanging valley, Sierra Nevada Mountains, looking across the canyon of the Merced River, toward the mouth of a tributary valley.

Do glaciers cover all polar lands? What conditions govern their distribution there at the present time?

Glaciers have had an important influence upon the shaping of the details of mountain slopes and canyons. It is even thought by some that the rounded canyons in glaciated areas, including the fiord canyons of Norway and Alaska, are in their essential features the work of glaciers; but there is much more reason in the view that they were made by running water and that their flooded mouths have resulted from a subsidence of the land.

The work which glaciers undoubtedly accomplish is the scraping off of all loose and disintegrated rock waste, the tearing away of projecting masses of solid rock, and a general grinding of the surface passed over to a degree varying with the hardness of the bed rock and the force of the moving ice.

Fig. 255.

A glacial cirque. North of Mt. Whitney, Sierra Nevada Mountains.

The stair-like character of the upper reaches of once glaciated canyons is due to differences in the resistance of the bed rock. The peculiar hummocky surface (Fig. 253), known as *roches moutonnées* from its resemblance to the backs of sheep, has been produced as a result of the unequal wearing away of the rocks over which a glacier once passed.

As a usual thing, the trunk stream in a given basin will deepen

its channel more rapidly than its tributaries, so that the latter will for a long time enter the main canyon or valley by a rapid or waterfall. It is also true that a large glacier will erode its bed more than a small one, and this fact has given rise to the view held by some geographers that hanging valleys (Fig. 254) in glaciated regions are the result of differential action of ice streams of

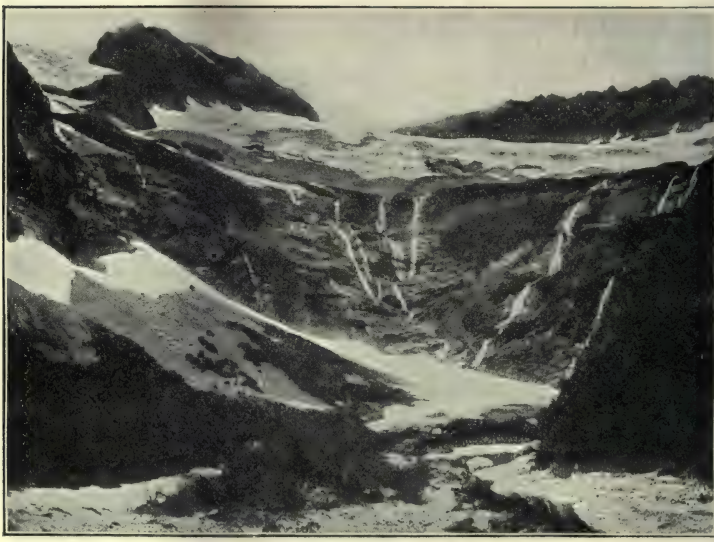

Fig. 256.

Glacial cirques. Summit of the Cascade Range. Note the streams fed by the glacier in the upper cirque.

unequal size. From the fact that similar valleys exist in nonglaciated regions, however, it seems more reasonable to believe that the main features of hanging valleys result from stream erosion previous to glaciation.

The steep-walled recesses at the very head of the canyons are known as *cirques*, and were the starting points of the glaciers once filling them (Figs. 255 and 256). Erosion cannot have pro-

duced the precipitous walls of cirques. The presence of vertical seams in the rock, the penetration of water, and the freezing and thawing about the edges of the ice are thought to be the conditions which have led to their formation.

If you live in a glaciated region and the bed rock is exposed, search for polished surfaces and scratches. Where will you be most likely to

FIG. 257.

Glacial cut and polished boulders. Quatsino Sound, northern Vancouver Island.

detect such markings, on rocks long exposed to the air or upon those from which the soil has recently been removed? Give reasons for your answer. What is the direction of the glacial scratches, if any are found? Upon what kinds of rocks will you be most likely to find glacial markings?

In Fig. 257 are shown some glacial boulders from Vancouver Island. Compare them with pebbles and boulders from a creek bed or lake

shore. Describe the origin of the flattened surfaces upon the boulders. Are the scratches all parallel? If not, explain how it is that they extend in different directions. Explain the origin of the peculiarly shaped dome in Fig. 252. In which direction did the glacier move?

Tell what you can about the causes of movement in a glacier. Describe the way in which it does its work of grinding away the rocks. What effect would a glacier have upon its bed if it carried along no rock

FIG. 258.

An unglaciated mountain summit, Sierra Nevada Mountains. Note the contrast between the glaciated and unglaciated portion of the peak.

fragments? The present glaciers in most cases appear to be slowly receding; what does this fact mean? What changes might cause them to advance again? Suggest possible causes for the Glacial period. Why are glaciated surfaces hummocky? What is the weight of ice compared with water? What do you think of the probability that glacial ice has excavated the deep fiord channels? Find out all you can about the fiords of Alaska and Norway.

Consult some text-book of geology as to the differences between

Continental, *Piedmont*, and *Valley glaciers*, and give illustrations of each. Mention all the indications of the former existence of a glacier which you might expect to find in a mountain valley or canyon.

Valleys due to Folding. — There are valleys formed by downward folds of the earth's crust, just as there are mountains arising from upward folds. The large intermontane valleys of

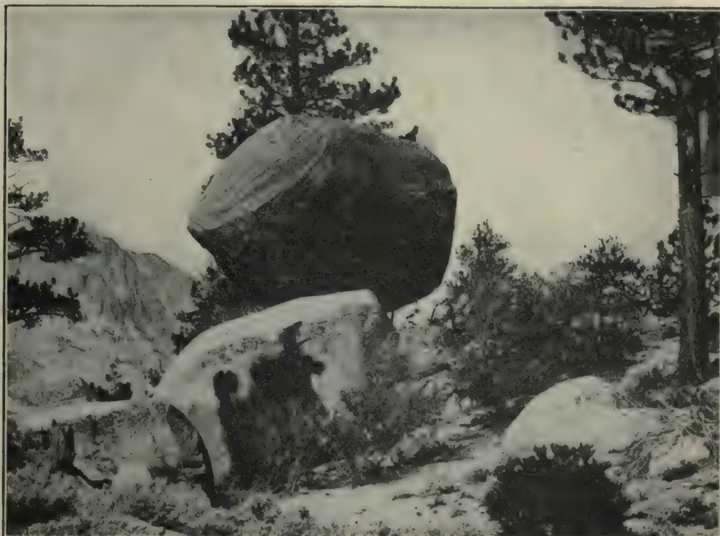

FIG. 259.

A perched boulder. Left by a glacier upon shore of June Lake, Sierra Nevada Mountains.

Colorado, known as "parks," are examples of valleys due to folding.

In what class would you place the Mississippi Valley? You can answer this question by calling to mind what has been said about the position of the strata upon the eastern and western borders of the valley compared with the position of those of the more central portion. Are valleys due to folding usually large or small? Of what origin are most mountain valleys?

FIG. 260.

A portion of California, showing the Great Valley bounded by the Sierra Nevada and Coast Ranges.

(From relief model by Drake.)

The Great Valley of California (Fig. 260) offers one of the best illustrations which we have of an extensive lowland region originating from a downward fold of the crust of the earth. The main outlines of this valley came into existence far back in the geographic history of the continent; and with each successive

elevation of the Sierra Nevadas upon the east and the Coast Ranges upon the west, its structural character became more pronounced.

The Great Valley is drained by the San Joaquin and Sacramento Rivers, which unite and break through the Coast Ranges about midway upon the western side. The valley is now entered by the tides, owing to the last submergence of the coast. At different times it has been an arm of the ocean, a brackish or a fresh-water lake, and a field for extensive delta accumulations in the form of débris fans.

What can you say as to the relative frequency of valleys of the type just described?

Fault Valleys. — Fault valleys are among the most interesting of the many remarkable features of the Cordilleran region. They are particularly characteristic of eastern California and the Great Basin region.

In places, faulting has occurred very recently; in fact, since the settlement of the country, as has already been noted in the case of the Inyo earthquake (p. 29). Where the displacement of the earth is recent, the valleys are shut in upon either one or both sides by steep-walled mountains. In many parts of the Great Basin, however, the date of the movements is so remote and erosion has done so much toward tearing down the mountains and filling up the valleys, that the origin of the latter is not always clear.

Some of the fault valleys are due to the dropping of an earth block as a whole (Fig. 261); in the case of others the block has been dropped upon one side only (Fig. 209).

Prepare sketches showing the formation of mountains and valleys by such displacements. When a valley and mountain range have been formed by displacement along a single fissure, where does the lowest part of the valley lie with reference to the steep face of the mountain? What is the explanation of the fact that Mono Lake lies so close under the eastern face of the Sierra Nevada Mountains?

Owen's Valley, in eastern California, is perhaps the most remarkable of the large valleys formed by the sinking of the crust. This valley is about one hundred miles long and from eight to ten miles wide. Upon the west is the Sierra Nevada fault scarp, the grandest in the whole country. Upon the east is the Inyo-White Mountain fault range, which in places is nearly as high and steep as the Sierra Nevada fault scarp.

FIG. 261.

A double line of faulting upon the west side of Owen's Valley, California. Sierra Nevada Mountains in distance; Alabama Hills in foreground.

In the formation of Owen's Valley, the long, narrow block, or blocks (for in places there are more than one), were displaced a vertical distance of five to ten thousand feet with reference to the mountain tops upon either side. The valley itself is now about four thousand feet above the level of the ocean.

A study of Owen's Valley shows that for a portion of its length it consists of at least two sunken blocks lying side by

side, one having gone down several hundred feet more than the other (Fig. 261). At the time of the earthquake of 1872, the lower block, that lying to the east and the one upon which the river flows, sank from ten to forty feet along its western edge. Similar movements have taken place along the borders of some of the valleys in Nevada and Oregon in very recent times.

FIG. 262.

A valley eroded upon the great earthquake zone of the Coast Ranges, California.

In the Coast Ranges of California there is found a series of valleys extending for a distance of more than four hundred miles along a zone of faulting and earthquake movement. A portion of this zone lies in a region of light rainfall; and springs, generally far apart in the adjoining country, are numerous along the line of disturbance. The presence of water and crushed rocks has caused erosion to be more rapid and has thus produced these interesting valleys (Fig. 262).

Find out what you can about the depression in which the Dead Sea lies and its extension to the north and south. This basin is thought to have been formed by a displacement similar to that which is so common in the western United States.

Migration of Divides: Stream Robbery. — It sometimes happens, partly from a difference in grade of two streams that head in the same divide and partly from the unequal resistance to

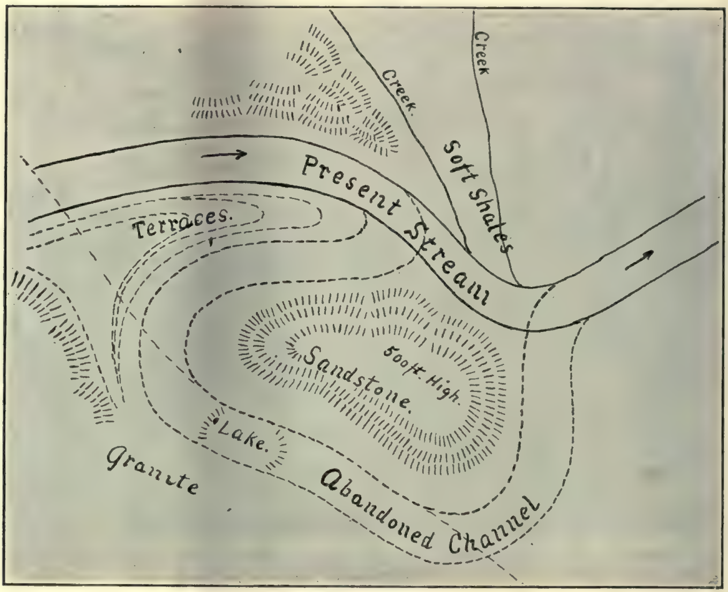

Fig. 263.

A portion of the Arroyo Seco, California: illustrating stream robbery. The stream has robbed itself and left a lake in the abandoned channel.

erosion of the rocks over which they are flowing, that one may deepen its channel more rapidly and extend its head back into the drainage basin of the other. In such a case the more active stream will *capture* a portion of the other.

Study the divides in your vicinity and see if you can discover any particular stream enlarging its basin at the expense of the basins of

p. 325

FIG. 264.

Lake in the abandoned stream channel shown in Fig. 263. Arroyo Seco Canyon, Coast Ranges, California.

adjoining streams. Try to detect the cause of such action. The streams of the Appalachian Mountains exhibit many such instances of robbery

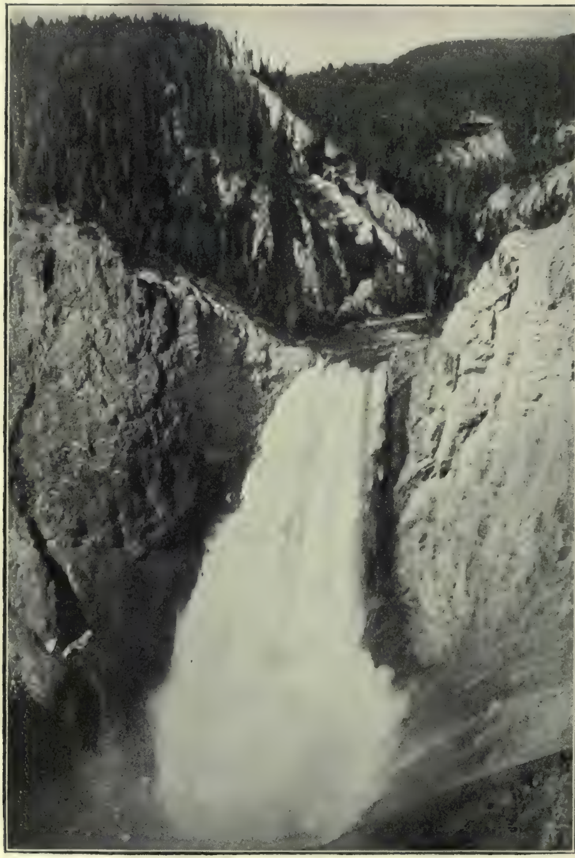

FIG. 265.

Great Falls of the Yellowstone, Yellowstone National Park.

and the diversion of drainage. Study out upon a contour map or relief map specific instances of this kind.

The change in the outlet of a large sheet of water as a result of the process mentioned above is shown in the case of Yellow-

stone Lake in the National Park. A study of the geography of the lake makes it clear that at one period in its history it emptied southwest through a low pass into Jackson Lake and the Snake River, instead of northward through Yellowstone River.

Using the Gallatin, Canyon, Shoshone, and Lake sheets of the Yellowstone National Park, seek for this ancient outlet and note its elevation above the present surface of the lake. Determine the average slope

FIG. 266.

Yellowstone River above the falls. Yellowstone National Park.

of the former stream flowing from the lake, as far as its junction with the Snake River. Trace the shore line of the lake when it emptied into the Pacific, and point out as nearly as you can the extreme northern end of the lake before the Yellowstone River came into existence. How much do you think the rim of the lake at this point rose above the surface?

Seek for the Lamar River and compare its canyon with that of the present Yellowstone River below the falls. Which appears to show a more advanced stage of development? What is the slope per mile from

the upper falls down to the junction of the Lamar River with the Yellowstone? The rocks through which the Yellowstone canyon is cut are soft and crumbling. How does this fact affect the rate of erosion? What is the nature of the surface of the country through which the canyon has been cut?

Yellowstone Creek, before it extended its head waters back and tapped the lake and became a river, had such a rapid fall and the rocks over which it flowed were so soft that what it has

Fig. 267.

Forks of the Merced River below the Yosemite Valley, California.

accomplished ought not to surprise us. Two Ocean Pass, southeast of Yellowstone Lake, is especially interesting because of the fact that through it there is water communication between the Pacific Ocean and the Gulf of Mexico. During high water fish come up Pacific Creek and, by means of branching streams in the marshy meadows of the continental divide, find their way into Atlantic Creek.

Study out this matter upon the Lake sheet, Yellowstone Park.

Waterfalls. — Explain the conditions which lead to the formation of waterfalls. Find out from the map the height of the Upper and Lower Falls of the Yellowstone. Two hard dikes lie across the path of the

FIG. 268.

Waterfall over the edge of a lava flow. San Joaquin River, Sierra Nevada Mountains.

river, and while they have offered much greater resistance to the water than have the decomposed volcanic rocks in which the canyon has been cut, yet they will not last for a great length of time (Fig. 265). When they are worn through, what will happen to the river above the present falls (Fig. 266)? What will eventually become of Yellowstone Lake?

The difference in the rapidity of erosion between trunk and tributary streams is clearly illustrated in the case of the Yosemite Valley. The valley, sunken three thousand feet between precipi-

FIG. 269.

A post-glacial gorge. The Flume, Franconia Notch, New Hampshire.

tous walls, is mainly the work of the Merced River. Bridal Veil Creek has cut down its channel to about half the depth of the main stream, and now reaches the valley by a waterfall nearly one thousand feet high. In the lower mountains, twenty

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FIG. 270.

Upper Yosemite Falls, California. Height, 1400 feet.

miles below the Yosemite, two forks of the Merced River of equal size unite, their channels being graded and inclosed in canyons of equal width (Fig. 267).

When a valley becomes partly or wholly filled with flows of lava, important changes are effected in the drainage and in the character of the streams. The San Joaquin River, in the Sierra Nevada Mountains, was thus interfered with. After the cooling

FIG. 271.

Wash plain of a glacial stream. Three Sisters, Oregon.

of the lava, which flowed down its canyon for some distance, the river made a new channel for itself, and at the end of the lava a waterfall was formed (Fig. 268).

Glaciers obliterate the preëxisting geographic features to such a degree that, when the ice melts and drainage lines are again established, the land is practically *new*, as is shown throughout the northeastern United States (Fig. 269). As a result of glacial action, Yosemite Creek has been turned out of an earlier channel

worn deep in one of the precipitous walls of the Yosemite Valley, and made to flow in a new one over the very top of this wall (Fig. 270).

Give examples of waterfalls or rapids with which you are familiar that are due to glacial action.

Prepare several sketches illustrating the conditions under which waterfalls would appear in a graded stream if the channel should be given

FIG. 272.

Deadman's Bar and gravel terraces upon the upper Snake River, Wyoming.

a slight increase in slope, supposing in one case the strata to be nearly level, and in another intersected by dikes of resistant rock.

Sketch a profile of the country between Lake Erie and Lake Ontario, showing the position of the strata and the particular cause of Niagara Falls. What condition will lead, as the falls retreat, to their lessening in height and final replacement by a series of rapids?

River Terraces. — In the earlier stages of the development of a river system, the water is engaged in down-cutting; but as its channel approaches a graded condition, the stream begins to

meander, and, attacking its banks, spends its energy in widening the channel and in building a flood plain.

Mention four factors which determine the actual rate at which a given stream will deepen its channel. What is the effect upon the operations of a stream carrying considerable silt, if its quantity of water be lessened? What will be the effect of greatly increasing the amount of silt?

Fig. 273.

Gravel terrace of the Columbia River, Washington.

At the melting of the glaciers which once covered so much of the northern United States, the streams were loaded with silt, gravel, and pebbles. Their channels were blocked and graded up until *wash plains* resulted. This process is illustrated by a little glacier-fed stream upon the slopes of the Three Sisters in Oregon (Fig. 271).

As the great glacier melted which once filled the basin about Jackson Lake at the head of the Snake River, a wash plain was

formed by the accumulation of glacial débris in the earlier valley. When the waters went down and gave rise to the present river, magnificent terraces were cut in the gravels at different stages (Fig. 272). Thus it may happen that under changing climatic conditions a stream will build a flood plain in a previously excavated valley, and then finally remove this material, forming a terrace at each successive stage.

FIG. 274.

The Mohawk River and Valley at Little Falls, New York. The Mohawk Valley is the most important natural route from the Hudson River to the Great Lakes.

A remarkable gravel terrace is found along many portions of the lower Snake and Columbia River canyons (Fig. 273). This was probably formed during the melting of the ice of the Glacial period.

Describe the conditions which led to its formation and to the present state of the Columbia River as shown in Fig. 273.

Similar terraces, although not always so distinct, characterize many of the streams throughout the Northern and Eastern States.

Search for gravel terraces in your locality. If there are no distinct benches along the sides of the valleys, you may nevertheless find here and there water-worn pebbles far above the present streams. What does the presence of such materials indicate?

FIG. 275.
Erie Canal, New York.

Terraces may also be formed in river valleys along a rising coast. This is shown by the Salinas River in the Coast Ranges of California, which, because of the fact that the land rose by stages, has cut at one point six different benches in the bed rock, each one representing the level of a flood plain at a certain time.

May this same appearance be brought about by a tilting of the land over which the river flows? Describe the economic importance of river terraces. Do you know of any towns or cities built upon river terraces? Explain the formation of bars in Fig. 272, and point out each of the terraces and the present flood plain.

FIG. 276.

Snoqualmie Falls and its electric power plant.

The Importance of the Waterways to People. — Rivers and the channels which they have worn across the country are of the greatest importance to man in many ways.

Describe all the uses which are made of streams. Find out all that you can as to the influence which the important waterways of the United States have had upon the discovery and settlement of the region. What are the disadvantages of the presence of rapids and

waterfalls in a river? What are the advantages? Describe the methods of transferring boats around rapids and waterfalls.

If a river is not large enough for navigation, and has not widened out its channel so as to afford bottom land for agricultural purposes, it may nevertheless possess economic importance.

Describe the Royal Gorge of the Arkansas (Fig. 291) and its value to the railroad. In what way are commerce and travel greatly facilitated between the Columbia plateau region of Oregon and Washington, and the coast? Mention any valleys or canyons with which you are familiar that have an important influence upon the life of your home.

It makes an important difference whether a region which people would like to occupy is in an early or late stage of geographic development. We might contrast in this regard the Colorado River, buried the greater portion of its length in a deep canyon, with the Ohio River in its broad valley. Rapids prevent navigation in the canyon of the Colorado; there is no bottom land for farming, and no opportunity to take out the water for irrigation. It is only in the upper and lower reaches of the river that its water is available for any purpose. The same thing is true of the Snake River, which throughout much of its course is buried in a canyon. It has been necessary to construct long and costly ditches in order to get the water from this river on to the arid plains of southern Idaho.

By tunneling underneath Snoqualmie Falls in Washington, Shoshone Falls in Idaho, and Niagara Falls, immense water power is obtained either for manufacturing purposes upon the spot or for transmission as electricity to great distances.

Find out all the cities that you can in the United States whose location has been largely determined by the presence of waterfalls. Will waterfalls determine the location of the cities of the future as much as they have in the past?

To what extent were the waterways used by the pioneer emigrant from New England to the Pacific coast? Trace out the main lines of migration upon a map and explain why the Missouri did not become a great highway to the Oregon Territory.

CHAPTER XV.

THE RIVERS OF THE UNITED STATES.

Introduction. — The important river systems of our country have been fully known for less than a century. In 1778, long before there was much definite knowledge of the great Northwest, Captain Jonathan Carver, a soldier of the French and Indian Wars, published a book purporting to give an account of his travels in the region about the head of the Mississippi. Much of the description is mythical, but it is quite interesting, nevertheless.

Carver says, in the introduction to the above work: "Of the four great rivers that take their rise within a few leagues of each other, nearly about the centre of the great continent, viz., the River Bourbon (Red River of the North), which empties itself into Hudson's Bay, the waters of the St. Lawrence, the Mississippi, and the River Oregon, or River of the West, that falls into the Pacific Ocean at the Straits of Anian." The idea of the four great rivers of the continent starting at nearly the same point is interesting; but in the case of the Oregon, or, as it is now known, the Columbia, the description is far from the truth. It is not probable that Carver ever saw this river.

At another point, Carver speaks of the rivers mentioned above, in the following language: "The waters of the three former are within 30 miles of each other; the latter, however, is rather farther west. That shows that these parts are the highest in North America; and it is an instance not to be paralleled in the other three quarters of the world, that four rivers of such magnitude should take their rise together, and each, after running separate courses, discharge their waters into

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Fig. 277.

Marshy lake in the forest region of northern Wisconsin. A scene typical of the Mississippi-Hudson Bay-St. Lawrence divide, where undrained glacial lakes, marshes, and sluggish streams abound.

different oceans, at the distance of 2000 miles from their sources; for, in their passage from this spot to the Bay of St. Lawrence east, to the Bay of Mexico south, to Hudson's Bay north, and to the bay at the Straits of Anian west, each of these traverse upwards of 2000 miles." The Straits of Anian referred to were

FIG. 278.
The Palisades of the Hudson River.

supposed to be the western entrance to a passage which navigators of the sixteenth and seventeenth centuries believed extended across the northern portion of North America.

Find out from your map the real distance from the head waters of the Columbia to the Hudson Bay-Mississippi divide and the nature of the intervening country. Is the highest part of a continent necessarily at the point where its large rivers rise? Is it so in the case of North America? Study, as bearing upon this point, the peculiar behavior of the Susquehanna River. Where does it rise with reference to the crest of the Appalachian Highlands? What causes may have led to its present anomalous course?

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FIG. 279.

Steamer running the Long Sault Rapid, St. Lawrence River. Note the character of the banks and the low relief of the adjoining country. Compare with the canyon of the Hudson River (Fig 280).

From what was given in an earlier chapter, describe the character of the divides of a new land, of a land of mature geographic features, and of an old land.

The Hudson Bay-Mississippi Divide. — Using an outline map, indicate the watershed separating the Hudson Bay, St. Lawrence, and Mississippi River systems. These three come together

FIG. 280.

The submerged canyon of the Hudson River.

in northern Minnesota at an elevation approximating fifteen hundred feet, in a strange and interesting land. The divides, instead of being sharp, are hardly discernible. The streams, instead of flowing swiftly, are generally sluggish, and are interrupted by innumerable lakes and marshes (Fig. 277) where immense numbers of waterfowl stop for a time upon their migrations. Forests cover all the land except those portions left bare and rocky by the grinding action of the glaciers. Traveling is scarcely possible except in canoes, and by making short portages one can go by water almost anywhere. There is a portage of less than a mile across flat land between the head waters of the Mississippi (Fig. 282) and the drainage into Rainy River and Hudson Bay.

Explain the origin of the marshes and lakes in this region. Are the geographic features new or old? What effect has the existence of so many lakes and marshes upon the regularity of the flow of the Mississippi River? Is the upper Mississippi or the Missouri marked by the more serious floods? Give reasons for your answer.

The St. Lawrence Drainage. — Describe the rivers connecting the Great Lakes and the manner in which vessels can pass from the ocean

FIG. 281.

James River at Vinita, Virginia. The broad flood plain has been eroded out of the coastal plain which appears upon the horizon.

to Lake Superior. What natural depression has made possible the Erie Canal (Fig. 275) across the state of New York? How has the recent subsidence of the Atlantic coast aided in the deflection of much commerce from the St. Lawrence basin to New York? Consult some history for a description of the route of the early canoe voyageurs from Ottawa to Lake Superior.

There are raised beaches along the southern shore of Georgian Bay, which become higher toward the northeast. Can you explain what this fact means? It is supposed that the land in the region of the Great

Lakes is now being slowly tilted toward the southwest. If this movement should continue, what effect will it ultimately have upon the St. Lawrence River system? At what point upon the southwest is the rim of its basin lowest (Fig. 131)? Find out what you can about the Chicago drainage canal.

The St. Lawrence River is doing very little excavating and varies little in volume at different seasons of the year. Give the reasons for

FIG. 282.

Typical topography of the Mississippi-Hudson Bay divide. The upper one-fourth mile of the Mississippi River. Lake Itasca, the source of the river, lies just out of sight behind the trees.

these unusual conditions. Why is the Ohio River, on the contrary, characterized by greater floods than the St. Lawrence, the Mississippi, or even the Missouri?

Consult the Niagara special sheet to see how far this stream has cut its gorge back since the close of the Glacial period, when the present drainage was established. There is a waterfall at the head of the gorge, rather than a rapid, because of the existence of a stratum of resistant limestone on the surface with soft shales underneath. The strata dip very gently down toward the south. Draw a section through the falls and

the foot of Lake Erie, and show what the effect of this dip will ultimately be upon the present lofty falls as they slowly retreat up-stream.

The Mississippi and its Tributaries. — Within the basin of the Mississippi River there are many different types of streams, as well as types of mountains drained by them.

Fig. 283.

Flood plain of the Mississippi River, with bluffs of the bordering upland. Southeastern Minnesota.

Contrast the general character of the upper Mississippi (Fig. 282) (Savanna, Illinois, sheet) with that of the lower portion (Donaldsonville, Louisiana, sheet). Illustrate each with a cross-section sketch.

Compare the drainage basin of the upper Mississippi with that of the Ohio, with regard to the area in each which has been subject to glaciation (Fig. 251). Basing your conclusion upon a study of the Charleston, West Virginia, sheet and the St. Paul, Minnesota, sheet, determine in which the geographic features are older and more mature. Compare the basins of the two rivers in regard to the relative abundance of lakes, and then call to mind what has already been said about the existence of lakes at a certain stage of the geographic development of a region.

During the melting of the glaciers all the drainage from the region of the Great Lakes was southward, until the Mohawk River, and later the St. Lawrence, came into existence. The Illinois River occupies one of these old glacial stream channels, while another extends from the western end of the Lake Erie basin down through the Wabash valley.

FIG. 284.

Flood upon the lower Mississippi.

The Appalachian Highlands, we must remember, consist of a series of parallel mountain ranges, to the east of which is the Piedmont Plateau and the Atlantic coastal plain. To the west of the mountains proper is the Appalachian Plateau, a maturely dissected region of nearly horizontal sedimentary rocks.

Review what has already been said of the distinguishing features of the Colorado Plateau (p. 222). Which exhibits the more mature geographic features, the Colorado or the Appalachian Plateau? How might the differences in the development of the features of the two regions have been brought about by climatic conditions?

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Fig. 285.

Relief map of the United States: showing the drainage basin of the Mississippi River.

The rivers which enter the Mississippi from the west take up their long journey across the Great Plains in channels usually broad and shallow. While the western border of the plains has

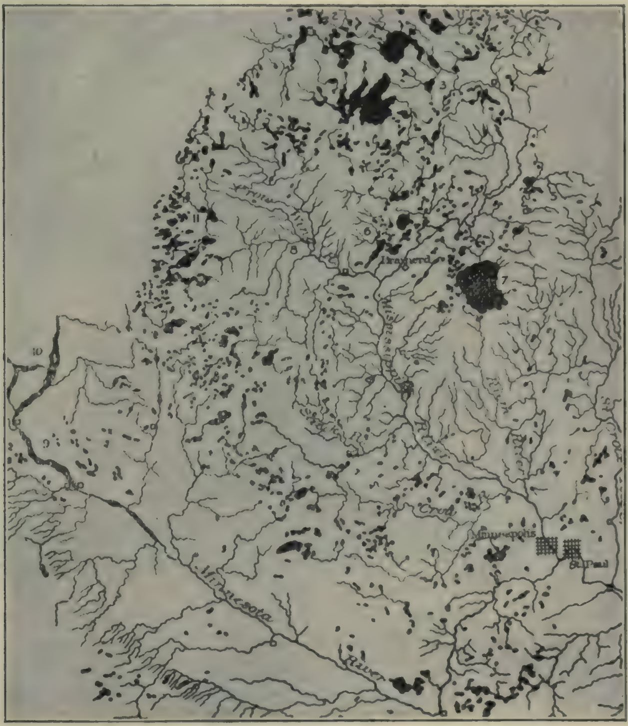

FIG. 286.

The lake region at the head of the Mississippi River: showing immature drainage features.

an elevation of five thousand feet or more, it is only in places that the chief streams, the Missouri, Platte, and Arkansas, are doing much in the way of deepening their valleys. It does not appear that they will ever cut canyons in the Great Plains, like those made by the streams upon the Pacific slope.

FIG. 287.

Delta of the Mississippi River.

Explain why there should be such a difference in the behavior of the streams upon opposite sides of the continental divide. In answering this question, discuss the effect of slope, volume of water, and the amount of

rock waste carried. Give a reason for the existence of shallow valleys in the region of the Great Plains and deep valleys in the Appalachian Plateau.

Point out the limits of navigation for commercial purposes upon the important tributaries of the Mississippi River. What would be the effect upon the streams of a slight increase in the slope of the Great Plains?

FIG. 288.

Great Falls of the Missouri, above Fort Benton, Montana.

The behavior of the Missouri River leads us to conclude that there has actually been a recent tilting of the region through which it flows. The lower and middle portion of the river occupies a shallow valley several miles in width. As we approach Fort Benton, the upper limit of navigation, the valley narrows; and a short distance above this place the river descends by a series of rapids and waterfalls extending through a distance of twelve miles (Fig. 288). Above Great Falls the river has cut a very slight trench in the plains, and at the Gate of the Mountains the flat, open country is left behind (Fig. 289).

Compare the Great Falls of the Missouri with the Falls of St. Anthony at Minneapolis, and with Niagara Falls, making use of the Great Falls, Montana, the St. Paul, Minnesota, and the Niagara Falls special sheets. In each of these cases the waterfall is due to layers of resistant rock overlying softer layers. Prepare a sketch illustrating such conditions.

FIG. 289.

The Missouri River above Great Falls, Montana. The river here has sunken its channel but slightly in the Great Plains.

The Platte is a remarkable stream, being nearly a mile wide in places and yet so shallow that canoes can scarcely be used upon it. In western Nebraska it is bordered by bluffs of some height (Fig. 290), while farther east it is but slightly sunk beneath the level of the plains. The muddy waters of the stream are inclosed by low banks and broken by innumerable bars and islands.

The Arkansas is a stream of great contrasts. Rising in the high mountains of the continental divide, it enters open valleys, and then buries itself in deep canyons as it cuts its way through the lower mountains (Fig. 291). The typical character of the

stream upon the Great Plains is shown in Fig. 292, from eastern Colorado.

Is the channel here being filled or is excavation going on?

The Rio Grande might almost be considered three different streams, for, owing to the desert-like country which it is compelled to cross, and also to the fact that much water is taken out

FIG. 290.
Platte River in western Nebraska.

for irrigation, it disappears for long stretches at two different places. The water of the upper division of the river at Albuquerque is so laden with silt that its channel is but slightly lower than the flood plain (Fig. 293). Hence it meanders over the valley, in one place cutting, and filling in another. Compare the river with the irrigating ditch (Fig. 48), near the same place. The Rio Grande does not, however, always flow through an open country. Much of its course is among mountains; and at one place, on the boundary line, it has excavated a deep canyon more inaccessible than the canyon of the Colorado.

Fig. 291.

Royal Gorge of the Arkansas River, Colorado.

The Snake and Columbia Rivers.—The basin of the Snake and Columbia Rivers should prove very interesting, for its surface is in greater measure the product of volcanic action than that of any other in the United States. Such a basin naturally presents

many unusual drainage features, such as underground streams, canyons with vertical walls, and lakes due to dams of lava.

Trace out upon a good map the course of the Columbia and the location of its source. What do you suppose is the reason for the presence of so many lakes along its upper waters?

FIG. 292.

The Arkansas River upon the Great Plains in eastern Colorado.

We will take first the Snake River, because of the strongly contrasting geographic features which it presents in different parts of its course, and, having followed it down to the Columbia, continue with the latter river to the ocean.

The Snake River takes its rise in that attractive region tributary to Jackson Lake, just south of the Yellowstone Park and east of the Teton Range (Fig. 212). After leaving Jackson Lake, the river flows for many miles through a valley whose bottom is buried in glacial accumulations. The channel is so choked with gravel that the water spreads over a broad plain, with interlacing

branches (Fig. 294). The southern end of the Teton Range is crossed in a deep canyon, and then the river emerges upon the vast lava plains of southern Idaho.

At Idaho Falls, near the eastern edge of the plains, the river has entrenched itself but slightly in the lava (Fig. 295). Below American Falls a canyon begins, which deepens until, after passing the Shoshone Falls, its bottom is six hundred feet below the surface of the plain (Fig. 296). The canyon is so narrow and the walls so precipitous that one is not aware of its existence until close to the edge.

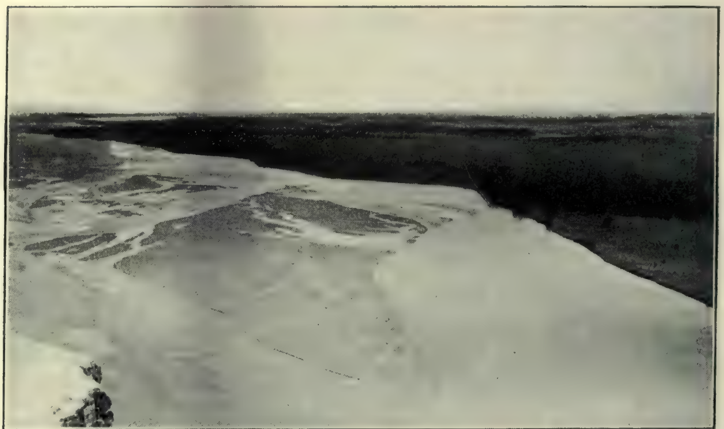

Fig. 293.

The silted-up channel of the Rio Grande at Albuquerque, New Mexico.

In southwestern Idaho the Snake River escapes from the lava for a time and flows across the soft deposits left in the bed of a former lake. Contrast this part of its course (Fig. 297) with those portions shown in Figs. 296 and 298, and explain the reasons for the difference.

Upon reaching the borders of Oregon, the river turns north and soon enters a canyon which for depth is not excelled even by

the Grand Canyon of the Colorado. The low gap which once existed in this region between the Blue Mountains of Oregon and the nearest spurs of the Rocky Mountains was long ago filled with lava having a thickness of several thousand feet.

In order to pass this barrier, the river has worn a canyon close to the granite mountains upon the east, and so deep and precipi-

FIG. 294.

The upper Snake River, Wyoming.

tous that there are but few points upon the rim from which the bottom can be seen (Fig. 298). Upon the western side a thickness of twenty-five hundred feet of lava has been cut through. Below that, the river encountered the granite. The river has now cut into these lower rocks thirty-five hundred feet, making a total depth of about six thousand feet.

The rocks of the canyon are somber in color, and the scenery is not as attractive as that of the canyons of the Colorado Plateau. It is probable that the great depth of the canyon is due to a gradual arching of the crust of the earth across the path of the river, the upward movement being so slow that the water was able to wear away the rocks and keep its channel clear.

As we approach Lewiston, the canyon decreases in depth, and remains comparatively shallow until its junction with the Columbia.

The Columbia River, in a seeming effort to escape the lava plateau of central Washington, swings far to the west to the foot of the Cascade Range, and then turns southward, inclosing a portion of the plateau known as the Big Bend. This part of the canyon, above the mouth of the Snake River, varies in depth from two thousand to three thousand feet.

FIG. 295.

Snake River at Idaho Falls, Idaho. The river here is just beginning its work of canyon cutting in the volcanic plains.

Below The Dalles, the lavas of the plateau have been arched upward forming the Cascade Range, and through this the Columbia has cut a very picturesque canyon (Fig. 299).

At the Cascades, enormous masses of rock falling from the canyon walls have so blocked the river that it has been found necessary to construct locks for the passage of boats.

For one hundred and fifty miles from the ocean, the level of the river is influenced by the tides, and navigation is unimpeded up to the Cascades. Above the Cascades, Celilo Falls and numerous rapids interfere with navigation, although there are long reaches upon the lower Snake River and nearly to the head waters of the Columbia upon which steamers ply.

FIG. 296.
Snake River Canyon below Shoshone Falls.

During the greater part of the year the Columbia carries but little silt, its waters being fairly clear. The drowned valleys tributary to the lower Columbia are being silted up, but the main river is not building a delta of any importance.

What does the presence of rapids and waterfalls in the Columbia and Snake Rivers indicate as to the stage of geographic development reached by these streams? Explain in detail the causes which have led to the flooding of the lower Columbia by the ocean. Compare this part of the Columbia with the Hudson River. Explain in full the reasons for the fact that the Columbia is building no delta at its mouth.

Next to the Snake River, the most important tributary of the Columbia is the Des Chutes. This river has its beginning in lakes and large springs upon the eastern slope of the Cascade Range in southern Oregon, and flowing north, has made for itself a deep and picturesque canyon through the lava of the plateau (Fig. 300).

Explain why it is that the walls of canyons cut in lava are sharper angled and more precipitous than those in granite.

FIG. 297.

Snake River in southwestern Idaho.

Read what you can find with reference to the part played by the Columbia River in the early history of the Oregon Territory. Read Irving's *Astoria*, which gives a most interesting description of the adventures of the first party that tried to descend the Snake River. Read also *The Oregon Trail*, by Parkman. The Lewis and Clark Expedition furnishes an account of the first party to cross the continent by the Missouri and Columbia Rivers. These narratives show the influence that geographic features exert upon the paths of exploration and discovery.

Review what you have learned about the conditions which led to the formation of the canyons of the Cordilleran region. What has been the influence of elevation, of distance from the ocean, of climate, and of rock structure? Refer to the canyon of the Virgin River (p. 135).

The Colorado and its Tributaries. — Try to picture in your minds the geography of the present continental divide before there were any rivers or canyons. Although it seems a long time to us, yet compared with the whole time that the land has existed, it was not long ago that the steep-walled canyons in this region were formed. The sharp peaks of the Rockies of

FIG. 298.
Grand Canyon of the Snake River.

Colorado had not been sculptured out; the crust of the earth had not been broken, giving rise to the Uintah, Wasatch, and Teton Ranges. The whole land was much lower; shallow lakes covered large areas of the country, and stretched almost continuously across the southwestern portion of the United States; and there were apparently no rivers at all resembling those of to-day.

The land began to rise and to be folded and broken. The rainfall increased, and large rivers took the easiest paths down the

slopes upon the opposite sides of the new continental divide. The surface over which the streams flowed was in some places resistant, in others easily worn away.

Review the origin of the Black Canyon of the Gunnison, and the Uncompahgre Valley (p. 161).

Movements of the earth continued long after the streams had established their channels; in fact, they are believed not to have

FIG. 299.

Canyon worn by the Columbia River through the Cascade Range.

ceased up to the present time. A portion of the plateau-like region was slowly raised across the course of Green River, giving us finally the Uintah Mountains; but the movement was so slow as not to interfere with the river. The high plateaus of southern Utah and northern Arizona were warped and broken, forming the Hurricane Cliffs and many others (Fig. 21).

The main streams continued their work of canyon cutting. The rounded divides at their head waters were eaten into and jagged peaks and ridges were sculptured out of them (Fig. 302).

The present plateau region was lifted in such a manner that the rocks were left horizontal or gently inclined to the north over a large portion of its area. As the forces of disintegration and erosion worked back from its lower margin toward the higher portions of the plateau, the alternations of hard and soft strata

FIG. 300.

Canyon of the Des Chutes River, Oregon. The canyon has been eroded in the lava of the Columbia Plateau.

gave rise to a series of steep cliffs. The boldest of these face the south, and the surface behind them forms table-lands, either flat or gently sloping to the north (Fig. 183). As a result of these conditions, the Green and Colorado Rivers flow through canyons and valleys. Below the Book Cliffs (Fig. 301), Green River has made a broad valley in a system of soft rocks; but a little farther south, where resistant strata were encountered, it has as yet done nothing but excavate a deep, dark canyon.

Between the junction of the Green and Grand Rivers and the

lower end of the Grand Canyon, much of the plateau immediately adjoining the Colorado River is cut up by a labyrinth of side canyons, so that it is impossible to travel along the brink of the main canyon. The lower portion of the San Juan, an important tributary from the eastward, passes across an exceedingly barren portion of the plateau where the horizontal

Fig. 301.

Book Cliffs, near Grand Junction, Colorado.

rocks and sculptured walls are magnificently shown (Figs. 181 and 303).

The Grand Canyon of the Colorado reaches its greatest depth opposite the Kaibab Plateau, where it is about five thousand feet. Here we may divide the canyon into two portions. The upper four-fifths is cut in nearly horizontal strata of limestone, sandstone, and shale. It is twelve to fifteen miles wide, and the walls present alternations of vertical cliffs and talus-covered slopes, the

cliffs being sculptured into an endless variety of picturesque forms (Fig. 304).

The lower one-fifth of the canyon forms what we might call the inner gorge, and it is cut mostly in granite. This granite is one of the most ancient rock formations of our continent. It was not, like so many other masses of granite, squeezed up in a

FIG. 302.

Jagged peaks of the San Juan Range, Colorado.

molten condition into the overlying sedimentary rocks, but formed the bottom of an ocean, in which animals lived and sediments accumulated, so long ago that we can form no real conception of the time involved. The animal remains, or fossils as they are commonly called, found here are forms low in the scale of life, and lived long before there were fishes or any other vertebrates.

Using the Kaibab, Arizona, topographic sheet of the United States Geological Survey, discuss the features of the Grand Canyon and of the plateaus to the north of it. Note the depth of the inner gorge, and the

depth and width of the main portion of the canyon. Note that there are few side canyons entering, particularly upon the south. Explain this fact. Note the slope of the river bed, and give your opinion as to whether or not the canyon is still being deepened.

Below the Grand Canyon, the Colorado flows through a succession of rocky gorges and desert valleys. Above the Needles, a group of sharp peaks in western Arizona (Fig. 305), there was once a lake, but the river silted it up, then excavated a canyon past the peaks, and formed a new valley in the former lake bed.

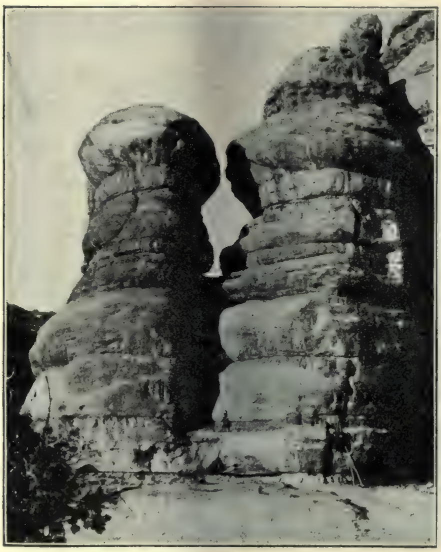

Fig. 303.
Sculptured walls of the San Juan Canyon, southeastern Utah.

The canyon of the Grand River, Colorado (Fig. 306), closely resembles the Grand Canyon. The Grand River has cut down through two thousand feet of horizontal rocks, and in places one thousand feet into the underlying granite.

The Mouth of the Colorado. — A little below Yuma, the Colorado River enters upon its vast delta plain (Fig. 307), and in the course of fifty miles reaches the head of the Gulf of California. Especially interesting is a study of the delta building of this river, because of the load of silt which it always carries and the absence of vegetation about its mouth.

As we approach the Gulf, the river is seen to divide into many shallow branches which wind between banks of bare mud.

p. 367

Fig. 304.

The Grand Canyon of the Colorado.

At high tide, and particularly at the time of the spring tides, the water at the head of the gulf rises and falls as much as thirty feet. The water is extremely shallow for a long distance out, and the land slopes so gently that there is a broad strip of muddy tidal flats. The tidal currents rush in and out of the mouth of

Fig. 305.

Colorado River at the Needles.

the river with great violence, producing that peculiar breaker known as the *bore.*

Navigation is difficult at the mouth of the river, because of the swiftness of the currents and the shallowness of the channels. In fact, the whole navigable portion of the river is marked by ever shifting sand bars.

The name Colorado means *red,* and was given to the stream by the Spaniards because of the color of its muddy water. Few

Fig. 306.

Canyon of Grand River, Colorado; 3000 feet deep.

other streams in the world are carrying so much silt in proportion to their size as is the Colorado. The water is never clear; while during the annual rise which occurs in May, June, and July, brought about through the melting of the snow in the Rocky Mountains, the river appears to be a mass of seething, boiling mud.

FIG. 307.

Relief model of the region of the lower Colorado River. Note the delta and the Salton sink.

(Model prepared under direction of J. B. Lippincott, U. S. Hydrographic Survey.)

It has been estimated by the Agricultural Experiment Station of the University of Arizona that the Colorado, during the year 1900, brought down sixty-one million tons of silt, sufficient to

cover fifty-three square miles one foot deep, if dry and loose, as we usually find surface material. The extreme muddiness of the water is shown by the fact that a column of water six inches in depth will, at season of partial flood, afford a layer of dried sediment one fiftieth of an inch thick; that is, the water carries one three-hundredth part of its volume of dry, hard silt. In the case of the Mississippi, the silt carried is given by Dana at one part in twenty-nine hundred. In order to carry this extraordinary load, the current of the Colorado must be very rapid. The average slope, between the point where it emerges from the Grand Canyon and Yuma, is a little less than a foot and a half to the mile. The Missouri, from the head of steam navigation at Fort Benton down to St. Joseph, has a slope of about one foot to the mile; but the Mississippi below the mouth of the Missouri flows upon a channel having a much less grade.

Through a time measured probably by hundreds of thousands of years, the Colorado has been removing the particles of rock waste from the mountains and plateaus about its head waters, and with the aid of these particles has been grinding out canyons. What has the river done with all this material? It has gone to fill up the arm of the ocean into which the river empties and to build the vast desert plains which stretch from the present end of the gulf, one hundred and fifty miles northward to the ancient shore line of this body of water.

Ages ago the Gulf of California extended north as far as Indio (see Fig. 307), and the Colorado River emptied into the gulf on the eastern side. The silt brought down by the river gradually built a dam across the gulf, cutting off the northern portion and forming a lagoon, or salt water lake. This soon dried up, leaving the salt deposits from which the district takes its name. Later a branch of the Colorado broke through into this depression and formed a new lake, the water of which was fresh, as is seen from the shells that still lie scattered on what were its ancient shores.

The delta continued to grow southward, and the channel by which a portion of the river, now known as New River, reached the lake was finally abandoned. Then the water in the lake dried up, leaving a depression two hundred and sixty-six feet below sea level. This is known as the Salton Basin, and only twice in recent years has any large amount of water reached it from the overflow of the Colorado River. In 1891 a lake was formed, having a length of thirty miles and a width of ten miles, but the water soon disappeared in the hot, dry air.

In the summer of 1905 the river washed out the head gates of the main canal, carrying water to the region about Imperial in the southern part of the Salton Basin, and began to find its way by means of one of its old channels into the Salton sink. At the present time (summer of 1906) the control of the river has been completely lost, and its flood of waters is pouring into the ancient lake basin, whose arid wastes are giving place to a vast lake. The waters are steadily rising. They have flooded the Salton salt works and compelled the railroad to keep busily at work building new tracks upon higher land. This lake bids fair to rival in extent the ancient lake whose shore lines are so plainly visible, unless the engineers can stop the flow of the river and turn it back into its old channel to the Gulf of California.

The waters of the Colorado are rich in materials for plant growth, and wherever they have been led out over the surface of the delta, the most luxurious vegetation springs up. What was until recently a barren desert now supports a population of several thousand people.

Compare, as far as you are able, the lower Colorado with the Nile, discussing the climate, soil, and productions.

In connection with this study of the Colorado basin, read, "The Black Gorge of the Gunnison," *Outdoor Life*, May, 1802; and Powell's *Exploration of the Colorado River*, Government Printing Office, 1875. Find out to what extent the Colorado River is navigable. Consult some history as to its discovery. A railroad survey has been run through the Grand Canyon. From a relief map determine what advantages, if any, a transcontinental line would have if built through the canyon.

CHAPTER XVI.

BASINS AND LAKES OF THE UNITED STATES.

The Formation of Basins. — Both the warring forces about which we have learned so much have been concerned in the making of basins. The building-up forces showed themselves first in the making of ridges and hollows upon the earth's surface. In the great hollows the waters gathered and formed the oceans, and thus protected those portions of the surfaces from the attack of the destructive forces. Above the level of the water envelope, however, the building-up and the tearing-down forces came in conflict with each other and thus were shaped the mountains, valleys, and basins with which we are familiar.

The internal forces warp, fold, and break the crust, and in many places pour out lava upon it, all of which work may result in basin-like depressions. The exterior, or tearing-down, forces also work in many ways in the formation of basins. In all regions once glaciated there are usually innumerable hollows occupied by bodies of water of varying size (Fig. 286). Other depressions are formed by landslides, by the dissolving of underlying rocks, in abandoned river beds, in delta regions, and along protected portions of shore lines. Basins are usually filled with water, but we must not think that this is necessarily the case.

What animals are concerned in the formation of ponds, and how do they work? Describe artificial reservoirs, their purpose, and manner of construction.

The various water basins are divided into classes according to their size. Mention three different classes and give examples of each.

Lake Basins. — Whether any particular depression does or does not contain a body of water depends upon the climate of

p. 374

Fig. 308.
The Great Basin.

the lands which slope toward it. So little water may fall within the drainage area of a basin that it will disappear in the earth and in the air before it has had opportunity to gather in the center and form a lake. On the other hand, there may be water enough for a lake, but not enough to cause the basin to overflow; or, as is the case in regions of abundant rainfall, the lake formed may rise until an outlet is found across the lowest point in the surrounding rim of land. The lake then becomes part of a river system.

Give examples from the United States and the Old World of each class of basins mentioned. Describe the character of the water of lakes without outlet. What lakes vary most in size and depth with the changing seasons, — those with or without outlets? There are lakes in some parts of the world where the rainfall is heavy, which have no visible outlet. Give an explanation of this fact.

CLASSIFICATION OF LAKES AND BASINS.

Structural Basins. — Movements of the crust and changes of climate usually take place so slowly that we do not become aware of them except through the records left by displaced streams and by terraces along lake and ocean shores.

Movements of the land known as warping are much less severe than folding, but are felt over a far wider area (p. 19). In a country of gentle relief warping may so disturb the existing drainage as to give rise to lakes.

The basin of Lake Superior is thought to be due largely to a down-folding of the earth's crust; while the basins of the other great lakes were probably formed by stream erosion early in the Glacial period, when the continent stood much higher than at present. The basins of all of them have been much modified by glacial action, and since the retreat of the ice, tilting or warping of the surface has further modified them.

After the melting of the continental glaciers the land sank much below its present level, and then, as it rose again, the sur-

face was slowly tilted toward the southwest, as we know from a study of the raised beaches about the lakes.

If this tilting should continue, where would it be likely first to disturb the St. Lawrence drainage and divert a part of its waters? Find out all you can about the Great Lakes, from some text-book of geology.

A warping of the surface has interfered with the former northward extension of the Mississippi basin. Lake Winnipeg

FIG. 309.

Scene near Red Rock Pass, southeastern Idaho: showing marshy bed of the former outlet of Lake Bonneville.

once emptied into the Mississippi River through the valley of the Red and Minnesota Rivers. The lake is now but two hundred and sixty feet too low to flow southward.

Turning now toward the West, we find that there faulting, rather than folding or warping, has been the important factor in the formation of basins. In many portions of the Cordilleran region, and more particularly in the Great Basin, nearly all the lakes result from the sinking of earth blocks. Mono Lake, for example, lying close under the precipitous front of the Sierra Nevada range, occupies the lowest portion of a basin due to the

sinking of the earth along the edge of these mountains. The movements forming the basin have been continued up to very recent times, — a fact shown not only by the effects of the last severe earthquake in that region (Fig. 24), but also by the smallness of the débris fans, which have not yet filled the basin sufficiently to crowd the lake away from the foot of the mountains.

FIG. 310.

The Provo terrace: ancient shore line of Lake Bonneville, southeast of Great Salt Lake.

As a rule, basins and lakes, particularly small ones, are short-lived as compared with other features of the landscape.

Explain why this is. Why might we expect the lakes of the Great Basin to be longer-lived than those lakes having outlets?

The Great Basin (Fig. 308) is one of the most interesting portions of our country. Before the uplift of the lofty mountains which shut it in upon the east and upon the west, the surface of this region had been broken into north and south mountain blocks, and sunken, basin-like valleys. Lakes and marshes occupied the

valleys, as we know from the presence of beds of coal and extensive deposits of clays like those in Death Valley.

Then the earth was broken again in many places, and the Sierra Nevada, Wasatch, Teton, and other ranges began to raise their precipitous faces. The present rivers commenced to flow, and where the slopes were steep soon buried themselves in canyons.

FIG. 311.
Terraces of extinct Lake Lahontan, Nevada.

With the rising of the lofty mountains upon the west, shutting out the moist winds from the Pacific, the Great Basin became more arid. Certain portions continued to sink until that basin-like depression known as Death Valley was about four hundred feet below the level of the ocean. This is the lowest dry land in the United States. Mention other basins, shut off from the oceans, whose bottoms are below sea level.

With the coming of the Glacial period the air became cooler and the precipitation greater, so that nearly all the valleys of the Great Basin came to be occupied by lakes, some of which grew to large proportions. The largest of all was Lake Bonne-

ville, named after a noted trapper and explorer of the Rocky Mountains.

At the time of its greatest extent, Lake Bonneville covered an area two-thirds as large as the present Lake Superior, and spread over a large portion of western Utah, reaching north into the borders of Idaho and west to Nevada (Fig. 308). It received such an

FIG. 312.

Rogers Sink, a playa lake, Mohave Desert, California.

abundant water supply from the lofty Wasatch Range, one of whose glaciers reached down to its shore, that it finally overflowed upon the northern side of the inclosing rim of land, and sent a mighty stream down through Red Rock Pass to join the Snake River (Fig. 309). The outlet was finally cut down several hundred feet; and then, in the course of time, the climate becoming drier again, the lake ceased to flow out at all and finally shrank to its present proportions (Fig. 308). At the time of its greatest height, Lake Bonneville lacked but very little of breaking over its southern rim and becoming tributary to the Colorado River.

Consult the St. George, Utah, sheet for the lowest point upon the southern rim, and note how slightly this is raised above the Escalante desert (Fig. 153), which was once an arm of the lake.

Another important lake contemporaneous with Bonneville is known as Lahontan (Fig. 308). This body of water occupied northwestern Nevada, and was extremely irregular in outline, having

FIG. 313.

Snag Lake, near Cinder Cone, California. The body of water is due to the dam of lava shown at the left of the picture.

long arms and many large islands formed by isolated mountain ranges. This lake never overflowed its rim. Can you tell where the water would have gone if the lake had had an outlet? Lake Lahontan is now broken up into a number of small lakes separated by desert valleys. Pyramid Lake, which receives its main water supply from the Sierra Nevada Mountains through the Truckee River, is the largest and most picturesque of these bodies of water (Fig. 145).

For interesting descriptions of Lakes Lahontan and Bonneville, you should consult monographs upon them published by the United States Geological Survey.

Owen's Lake, now intensely alkaline, overflowed during the high-water stage and sent a broad river south into a number of large desert basins in southeastern California, which are now

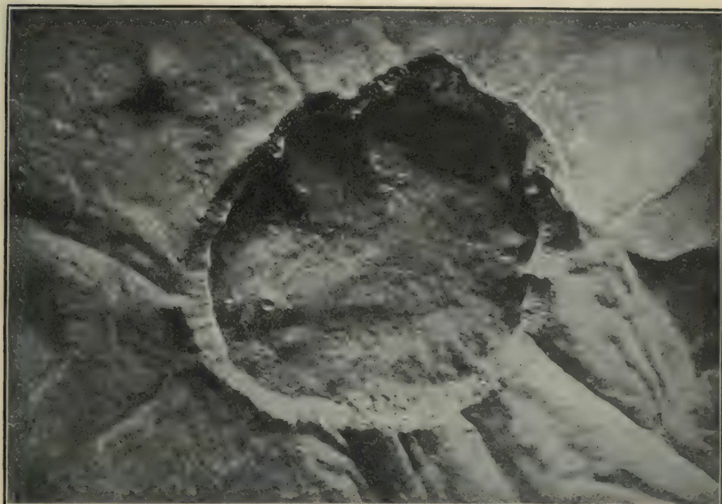

FIG. 314.

The rim and basin of Crater Lake.

(From a relief model prepared by the United States Geological Survey.)

occupied by marshes containing borax, soda, and salt. The dry bed of the old river forms a convenient route for a wagon road.

Hundreds and possibly thousands of lakes filled the basin-like valleys over this vast desert region; but now they are gone, and have left in their places stretches of white salt or barren clay beds (Fig. 59).

The waters of these lakes did not dry up at a uniform rate, but by irregular stages; and at each period, when a series of

years of uniform rainfall held their waters at one level, beaches were formed and cliffs cut in the shores. These are beautifully preserved upon the ancient shores of Lahontan and Bonneville (Figs. 310 and 311).

Many basins once occupied by permanent lakes now contain water during only a portion of the year. A body of shallow water

FIG. 315.

Wizard Island. An extinct volcano in Crater Lake, Oregon.

gathers in such a basin after the winter storms, only to disappear with the coming of the hot, dry air of summer. Most of the year its bed is a smooth, hard surface of yellow clay (Fig. 312).

With the present climate, most of the valleys of the Great Basin rarely contain any standing water. The few small streams flowing down the mountain slopes sink in the loose material of the débris fans shortly after leaving the rock-rimmed canyons.

The term *sink* is applied especially to those basins which contain little or no water upon the surface. The sink of the Mohave

River in southeastern California is a good example. The sinks of the Carson and Humboldt Rivers are also examples, although in these, shallow but permanent lakes exist.

From the best available maps trace out the courses of the larger streams of the Great Basin. Trace out upon the large contour map of the United States published by the United States Geological Survey the

Fig. 316.

Soda Lake, Nevada : occupying an old crater.

position and elevation of the barrier which separates Death Valley from the ocean and from the Colorado River. Find the lowest point upon the rim of Lake Lahontan.

Playa Lakes. — The discussion in the previous paragraphs has prepared us to understand without further explanation the conditions governing a class of lakes which is especially characteristic of the Great Basin, or, in fact, of similar desert regions in any portion of the earth. A lake which comes and goes with the changing seasons, a lake which may exist as a broad shallow sheet of water during the cool, wet portion of the year, but

which entirely disappears under the influence of the hot summer sun, is known as a *playa lake* (Fig. 312).

Lakes formed by Lava Dams. — In the Cascade Range of Oregon and California there are lakes due to lava flows blocking the drainage of valleys. Such lakes rarely have a surface outlet, the water finding its way out through the crevices in the lava.

Fig. 317.

A rock-rimmed glacial lake. Salmon Range, northwestern California.

Snag Lake, California, has resulted from the eruptions at Cinder Cone, where took place the last lava flow in the United States (Fig. 313).

A peculiar lake of the same kind occurs near the Three Sisters, a group of volcanic peaks in central Oregon. A large stream of lava flowed down a valley leading to the Mackenzie River, and blocked the mouth of a tributary valley. A lake was formed in the latter valley, but did not rise sufficiently to run

over the lava, because of an underground outlet. The stream coming down the main valley has picked out a channel over the surface of the lava, so that below the lake there are two water courses, one on the top of the ground and the other about two hundred feet underground.

FIG. 318.

Looking up Echo Lake, New Hampshire. This basin is the result of glacial action.

Will lakes of this class finally be drained or will they fill up with silt?

Crater Lakes. — There was once upon the summit of the Cascade Range in southern Oregon a great volcano, probably about the size of Mt. Shasta. During a period of unusual activity the foundations of the mountain were melted away; and the whole was engulfed in a fiery, seething *caldera.* The molten matter in the crater, which was five miles across, was drawn down into the

earth until the opening was four thousand feet deep. Then, after a time, the lava in the crater crusted over and a new volcano was formed in it. From this came lava and then ashes and lapilli, until a cone was built up to a height of nearly three thousand feet above the bottom of the old crater. This cone, lofty as

FIG. 319.

Lake due to a glacial moraine. Convict Lake, eastern slope Sierra Nevada Mountains.

it is, does not, however, overtop the inclosing walls. When the eruptions ceased, water gathered in the crater until it was half full, forming a lake which, though nearly two thousand feet deep, still lacks eight hundred feet of overflowing at the lowest point. There is little drainage into the lake, for the slopes all lead away from it; and the fact that the water stands at an almost constant level shows that precipitation is balanced by evaporation.

p. 387

FIG. 320.

Rock-rimmed glacial lake, 10,000 feet elevation, Sierra Nevada Mountains. Shows glacier-swept surfaces and stunted foxtail pine.

The former existence of a lofty mountain (p. 276) where Crater Lake (Figs. 314, 315) now stands is shown by many facts. Several canyon-like valleys extend up to the rim of the crater and are there truncated by it. The heads of these valleys must have been far up the slope of the vanished mountain.

Point out the valleys referred to, upon the Crater Lake special sheet.

Upon the highest points of the rim of the lake are rocks polished and rounded by glacial action.

Explain how this fact supports the theory of a former mountain. Does it give us any information as to the time at which the mountain fell in? Find out from any accessible source our reasons for believing that the mountain was engulfed, rather than blown up. Compare the phenomena presented here with those of Coon Butte, Arizona, already referred to (p. 267).

We have already learned something of Soda Lake, Nevada, which occupies a crater more than a mile across (p. 270). The rim of the crater is but slightly raised above the level of the surrounding country, while the depression within is less than three hundred feet. We know that this is an explosive crater, from the fact that the rim is formed of fine lapilli and small volcanic bombs, while similar materials are scattered over the surrounding desert plain. The water of Soda Lake, as the name indicates, is so richly impregnated with soda that the crude product is prepared here in commercial quantities (Fig. 316).

Why is there no lake in the crater of Coon Butte, Arizona? Find out what you can about other crater lakes in the world.

Glacial Lakes. — Most of the lakes scattered throughout the northern United States and in the mountains of the West are of glacial origin (Figs. 317, 318).

With the aid of a map showing the boundaries of the once glaciated area in the United States, point out the lakes lying to the south of it, and note their relative number.

Glacial lakes may naturally be divided into two classes: (1) those occupying basins dug out of the solid rock by the ice; and (2) those lying behind moraine dams or in hollows left at the retreat of the ice.

FIG. 321.

Lake occupying depression in a glacial wash plain, Washington.

If your home is in a region once glaciated, determine which of these classes of lakes is more common. Review the origin of wash plains and kettle holes. If the latter become filled with water, ponds and lakes are formed. Miniature kettle holes may be found along the sandy or gravelly shores of lakes and rivers at the melting of the ice in the spring. Describe their manner of formation.

All the large canyons in the high mountains of the West and Northwest are marked by lakes of glacial origin. In the Sierra Nevada Mountains they may be counted by the thousand. Each canyon, where the conditions have been favorable, contains a string of such lakes. The lower ones are held behind moraines,

for here the glacier dropped most of the waste rock material. Point out the moraine in Fig. 319. In the upper reaches of the canyons the surface was swept bare by the ice, and although there are some moraine lakes, the greater number lie in rock basins (Fig. 320).

Fig. 322.

A wave-cut terrace upon the shore of Lake Iroquois, New York: an extinct glacial lake.

Has the varying resistance of the bed rock anything to do with the position of such rock-rimmed basins? Are they likely to be shallow or deep?

Study any lakes to which you have access and determine the nature of the basins in which they lie. Does the stream at the outlet of any particular one flow over bed rock or over loose fragmental material?

If it flows over pebbles and boulders, are they or are they not like the bed rock in the neighborhood? How would this affect your ideas as to the origin of the lake?

Lake Ontario has a depth of seven hundred feet, and its basin is thought to have originated through stream erosion previous to the spreading southward of the continental ice sheet. It must be, then, that it is glacial débris which formed a dam across the old valley and thus gave us a lake, instead of an arm of the ocean connecting with the Gulf of St. Lawrence.

FIG. 323.

Coastal lagoons, Northern California.

Delta Basins and Lakes. — A river is continually shifting its channel over the surface of its delta.

Give your reasons for the lack of permanency of such channels. Illustrate by a study of the delta of the Mississippi River. Explain how such bodies of water as Lake Pontchartrain were inclosed by the delta of the Mississippi. What is the origin of the numberless bayous and lagoons along the lower portion of that river?

The Salton Basin in the Colorado Desert (formerly a part of the Gulf of California) has at various periods been occupied by a delta lake (see p. 371).

In the arid valleys of the Great Basin region there is at present an imperfect drainage system due primarily to the light rainfall. This has, however, been made much more pronounced by the settling of blocks of the earth's crust and the accumulation, at points in the valleys opposite the mouths of the large mountain canyons, of vast quantities of waste rock in the form of débris

FIG. 324.

A tidal lagoon. Coast of Southern California.

fans (p. 205). Such fans have blocked the valleys in very many places, so that if the climate should again become moist, the region would be thickly dotted with lakes. With the overflowing of the water in these basins, drainage lines would be reëstablished, and, owing to the amount of silt and the incoherence of the accumulations, the lakes would rapidly disappear. Explain how this would be brought about.

Coastal Lagoons. — Both the Atlantic and Pacific coasts of the United States have recently undergone subsidence, and across

To face p. 393

FIG. 325.

many of the bays formed by the flooding of river valleys the currents have thrown up barrier beaches.

From a study of coastal maps, explain in detail under what conditions a barrier beach will be formed across a bay, and what the conditions are that will prevent the formation of such a barrier. When will the barrier be permanent? In the latter case, what will become of the lagoon in

FIG. 326.

Lake formed in the canyon of the Kern River, by a great rock slide. Sierra Nevada Mountains. The rock slide is shown upon the left.

the course of time? Illustrate the different cases, either from the map or from your own observation.

A remarkable illustration of the formation of a barrier beach from headland to headland is found upon the coast of Northern California (Fig. 323). These lagoons receive very little drainage.

In what way will this fact affect their history? Make a cross-section sketch of the silted-up lagoon shown in Fig. 324, and give its history as fully as you can. This is from the Oceanside, California, sheet.

Landslide Lakes. — In regions of steep slopes, earth or rock slides frequently occur during portions of the year when the ground is saturated with water. Should a mass of rock become so loosened that the pull of gravity is greater than the resistance of the rock, it will slide into the valley or canyon below, and a lake

FIG. 327.

West wall of the Grand Coulée, 800 feet high. North of Coulée City, Washington.

will be formed in the portion of the channel thus blocked (Fig. 326). Such a lake will, however, be short-lived if the stream possesses much volume, for the loose material of the dam will be rapidly carried away.

Describe any basin which you have ever observed due either to the formation of a débris fan across a valley or to a landslide.

Coulée Lakes. — In the depressions of river beds which have been permanently abandoned by the streams that made them,

lakes are frequently found. To a body of water occupying such a basin the name *coulée lake* has been given.

A river may be diverted by robbery and drained away in another direction, or it may disappear owing to a change in climate. The outlets of Lake Bonneville at Red Rock Pass and of Owen's

FIG. 328.

Lake in the Grand Coulée, central Washington. Bed of the Columbia River during a portion of the Glacial period.

Lake during the Glacial period were large rivers, but now their beds are dry, except for marshy lakes (Fig. 309).

One of the most interesting examples to be found in the United States is the Grand Coulée in Washington (Fig. 327). During the Glacial period the Columbia River was blocked for a time by a glacier which extended down into its canyon from the Cascade Range. The river was then turned across the Columbia Plateau and dug out the canyon now known as the Grand Coulée. When the glaciers melted, the river returned to its former channel, but left its temporary bed dotted with lakes (Fig. 328).

The northern portion of the Grand Coulée has precipitous walls of lava four hundred to eight hundred feet high. South of Coulée City the slope of the channel is greater and the walls are not so high; but for twenty miles it contains a series of picturesque lakes set between vertical walls of black lava. The great volume of water once plunging down the sloping plateau dug out deep, irregular hollows; while the resistant points of rock so checked the current as to form huge gravel bars which appear here and there along the channel, in just as perfect condition as when the water stopped flowing.

The upper lakes are clear and quite pure; but toward the southern end of the series the water becomes increasingly alkaline; and the last one, Soap Lake, is so strongly impregnated with soda and borax that the water immediately forms a froth when one attempts to wash a garment in it.

Explain fully the fact that a lake with an outlet will remain fresh, while one having no outlet soon becomes filled with salts of various kinds. From what two sources are the salts in the water of a closed basin derived? How can you detect mineral substances in solution in spring or river water? Show by some experiment that there are soluble materials in the soil. Have you ever seen whitish deposits in the beds of dry streams or about the borders of ponds that were drying up? If so, tell what you can about their origin.

Pound up a piece of fresh rock and another of decomposed rock of the same kind and wash the powder of each separately. Evaporate the washings and find out which affords the more soluble material. Will decaying granite furnish the same soluble materials as a piece of dark lava? What are the most common of the soluble constituents found in water and in the soil?

Lakes without Outlets. — The lakes in the United States that have no outlet are mostly confined to the Great Basin. The water of all lakes of this kind contains more or less mineral matter in solution. The water is usually so alkaline or salty that fish cannot live in it, and it cannot, of course, be used by any animals except a few low forms.

The water of no two of these lakes is alike in composition; in fact, they differ so greatly that it is difficult to understand how this difference came about. We must remember, however, that the rocks in the different basins are frequently unlike, and besides, the histories of the lakes have not all been the same.

Fig. 329.

The white, salt-encrusted shore of Great Salt Lake.

Dissolve some salt in a dish of water; then let it stand and note what takes place as it evaporates. Experiment further by dissolving some salt in a basin of water, and then adding a little more than the same quantity of soda. Now evaporate the water until a white substance begins to separate out and collect upon the bottom. Taste this and see whether it is a mixture of salt and soda or pure soda. As soon as a liquid is saturated for any given salt, that salt will begin to crystallize so that we can obtain it almost pure. This principle enables us to separate in commercial quantities the salts in the lakes of the Great Basin.

In the same manner nature sometimes separates the salts in these lake basins. Let us suppose that some one of the lakes contains so much lime that the water is saturated for it long before it is saturated for the other minerals in solution; then, if the lime is deposited upon the bottom, sand and mud may be

Fig. 330.

Willow Lake, Northern California. Partly overgrown by a floating meadow.

washed over it, permanently burying it and leaving the waters of the lake comparatively free from this substance.

The lakes of the Great Basin contain large quantities of such minerals as soda, salt, borax, lime, and Glauber's salt; but usually not all of these are found in the same body of water in any considerable amount. The water of Great Salt Lake is remarkable for being an almost saturated solution of common salt. There is now little lime in the water, for it has mostly separated out in

the form of granular oolitic sand, which is scattered over the bottom. Glauber's salt (sodium sulphate) is estimated to be present to the amount of thirty million tons. When the water becomes cold in winter, this salt is precipitated in large quantities and can then be gathered; but with the return of summer it is again dissolved in the water.

Fig. 331.

Lake being replaced by a meadow. Western Montana.

Show by some simple experiment that warm water will dissolve a greater quantity of salt than cold water.

Salt is obtained upon a large scale from the water of the Great Salt Lake. The brine is pumped into ponds, where it is allowed to settle. The clear water is then drawn off into other reservoirs, where, under the influence of the dry air and hot sun, it evaporates, until from the saturated solution a certain amount of salt is precipitated. The water, with the impurities, is then drawn off.

In Mono and Owen's Lakes, soda and salt are the leading constituents, being present in nearly equal quantities. The soda, in particular, is of great commercial value, and as the water is saturated for it first, it is easily obtained. The water is pumped into basins, where it evaporates; the soda separates, settles to the bottom, and is then shoveled out.

FIG. 332.

Cypress trees in the Dismal Swamp, Virginia.

Lime was precipitated in curious shapes upon projecting points of rock in the bed of ancient Lake Lahontan; and as the water dried up, picturesque domes and pinnacles appeared (Fig. 145).

In Mono and Great Salt Lakes there are countless numbers of a species of brine shrimp. Algæ are found in the latter lake, and its shores at a certain season are covered with the larvæ of a fly. Owing to the fact that the water of Great Salt Lake is a

saturated brine, it is extremely dense. The wind cannot raise waves of any size upon the surface of the lake, and bathers find it impossible to sink.

Mineral Deposits in Dry Lake Beds. — In southeastern California there are numerous basins once occupied by lakes, but now practically dry. Upon some of these lake beds valuable deposits of salt, borax, and soda have been found. The Death Valley basin contains all three of these minerals.

If this basin had been occupied by the ocean, would you expect to find borax and soda? What other reason is there for believing that the ocean never reached this depression?

In the eastern portion of the Mohave Desert there is a sink known as the Danby salt marsh, where there are thick beds of rock salt. It is believed that the ocean once penetrated, not only to the Salton Basin in the Colorado Desert, where there is a great quantity of salt, but to this basin as well, for there are no high encircling mountains to shut it out.

When the lakes of this region dried up, the various salts remained mixed with the mud upon their bottoms. The surface finally dried out; but the water below kept creeping upward, bringing with it the soluble salts, which, as it evaporated, were left spread out over the surface as a soft white layer. As fast as this layer is removed in the process of mining the salts mentioned, the supply is renewed from beneath.

Illustrate from some common examples the meaning of *efflorescence.*

The Disappearance of Lakes. — The complete disappearance of lakes through evaporation is confined to the arid portions of our country, although no lake is free from the action of some destructive force. The streams are continually at work filling basins with the rock débris which they are bearing from the highlands; while those basins whose lakes overflow are being destroyed also by a cutting down of their channels at their outlets.

State from your own observations which of the two latter processes is the more important. How does the water flowing into a lake during periods of flood compare in muddiness with that flowing out? Is the silt taken through the lake and out again, or is it dropped in the lake? How does this condition affect the erosive power of the stream at the outlet? Examine any lakes to which you have access, to see if there are

FIG. 333.

Lake Drummond, Dismal Swamp, Virginia.

indications that they were ever higher than they are now. Examine the condition of the outlet; does the water flow swiftly or slowly?

Note if there are any deltas being formed where the streams enter the lake. What parts of the lake are the shallowest? Prepare a cross-section sketch of some delta which you can examine, showing its manner of growth and the relation of the surface to the bed of the adjoining portion of the lake. Where does the coarsest material brought by the streams accumulate? Where does the finest go? Find out all you can about the influence of vegetation upon the filling of a lake basin. Mention some of the important water plants found growing about the margins of lakes. Find out what you can about floating meadows and islands.

There is a genus of mosses known as *sphagnum*, which in some parts of the earth performs a most interesting part in the destruction of lakes. The moss spreads over the surface in a layer, which finally becomes so firm that particles of silt and decaying vegetation collecting upon it afford footing for grasses and even small bushes. Under the weight of a person the floating layer will vibrate, but the surface is not easily broken through. Of such a nature are the floating meadows of Willow Lake, in northeastern California (Fig. 330). The lake receives almost no silt, and in course of time must be entirely replaced by an immense deposit of moss and other vegetation.

What vegetable product is dug from swamps in many parts of the world and used for fuel?

In almost any locality you will be able to find lakes which have either wholly or in part been replaced by meadows. Point out any meadows in your locality which have evidently been derived from the filling of lakes. Observe the different zones of vegetation about the borders of a marshy lake. If your home is near the ocean, note the successive steps in the silting up of a lagoon and its transformation into a salt marsh and finally into a meadow.

Importance of Lakes. — Describe the importance of the Great Lakes as a highway for travel and commerce. What effect have these lakes upon the climate of the adjoining lands?

Mention the various uses of any lakes with which you are familiar. What are the probabilities of the occurrence of disastrous floods in a river basin containing many lakes? What uses are made of the moss from our northern swamps? Find out what you can of the origin and character of the Dismal Swamp of Virginia (Fig. 333). What effect must the draining and clearing of the swamps of the Northern States have upon the streams?

Describe any artificial lakes or reservoirs which you have seen. What kind of a place is sought after when it is desired to build a reservoir? Mention some of the different ways in which reservoir dams are constructed. Mention some of the chief uses of reservoirs in different parts of our country.

In review, describe all the different conditions which give rise to lakes with a rim of bed rock surrounding them upon all sides.

CHAPTER XVII.

THE GEOGRAPHY OF COAST LINES.

The Coast Line. — The line of meeting of the ocean and the land is called the *coast line.* As the land is almost always undergoing slow movement, either up or down, so the coast line cannot be a stationary one, but moves back and forth. When the dry land encroaches upon the ocean, we say that the former is rising; but in reality we do not know but that the ocean bed is sinking at some spot, in this manner exposing more of the earth's surface above the water.

How does the supposition that the earth is becoming more mountainous as it grows older affect our view of the relative proportion of land and water in early times, compared with that now existing? Are the changes in the shore line, caused by movements of the earth, noticeable sooner along a low coastal region or along one in which the land rises steeply?

What kind of a country may you expect to find back of a deeply indented coast? For answer study New England and Alaska. What kind of land usually lies back of an even and regular coast? Illustrate with specific cases. Explain in detail how the direction of the mountain ranges near a coast affects its regularity. Give a detailed description of the characteristic differences between the surface of the land and the floor of the ocean adjoining.

The Effect of Waves upon the Land. — If it were not for the erosive action of the waves and currents, the seacoast would scarcely differ from the shores of small lakes and ponds. The work of the waves, however, — due to the strength which they gather passing over a large body of water, — is second only, in its effects upon the land, to the streams that flow down the slopes.

A part of the
SAN DIEGO, CAL.,
sheet (U. S. Geological Survey), illustrating the formation of a barrier beach behind a long, narrow headland.

Scale of Miles
1 2 3

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FIG. 334.

Study carefully any wave-cut cliffs within your reach. Note at what level the waves do the most of their work. Do they cause the cliff to recede by undermining it or dashing up over it? What is the general character of the headlands compared with the lands lying behind the bays? Where do you look for boulder beaches? Where are pebbly and sandy beaches found? Where is the bottom and shore likely to be muddy? Along what portions of the shore are the currents

FIG. 335.

Meeting point of the land and the water. Coast of Northern California.

and waves the strongest? If you could go out underneath the ocean from a boulder beach, you would pass in succession over pebbles, sand, and, far out in deep water, muddy sediments. Explain why this is so.

It is the general tendency of the waves to smooth off an irregular coast, wearing away the headlands and filling up the bays.

Study Fig. 353 and tell what is taking place. Why is the shore so irregular? Is it being smoothed or is it growing more irregular? Explain the distribution of the rocks and sand in Fig. 338.

We may look for the most pronounced wave action along those coasts which are now sinking or have recently done so. The island of Helgoland, in the North Sea, which had an area of one hundred and twenty square miles in the year 800, has now been reduced to one-third of a square mile and bids fair to disappear entirely (Fig. 51). Many portions of the English coast also are rapidly receding.

FIG. 336.

A wave-cut shelf near Point San Pedro, California. The land has risen three feet since the shelf was made.

Review what has already been given (p. 62), upon the work of the waves. What are the tools with which they wear away the land? Describe the formation of pebbles and sand. Compare some beach sand with the grains of quartz in a piece of crumbling granite, and tell how they differ. What becomes of the fine clayey portions of the rock torn from the shore?

What are the conditions which lead to the formation of bars? From a study of the Coast Survey charts of some of the leading bays, as, for example, New York, San Francisco, and the mouth of the Columbia, locate the position of the bars and compare the depth of water upon them with the depth within and without.

Use the Atlantic City, New Jersey, topographic sheet for a careful study of the bars and beaches which have been formed upon a low coastal plain.

Prepare a sketch showing a section of a cliff, the surface of the water, and the sloping bottom. Base this upon observations which you have made upon lake or ocean shore.

FIG. 337.

A pebble beach across a lagoon, Southern California. This beach is not now reached by the waves because of a recent uplift of the land.

While great waves, such as those occurring upon the ocean during a storm, disturb the water to a depth of hundreds of feet when they break, yet their erosive action upon the shore reaches only a little distance below the surface.

The thick growth of marine plants over the rocks offers in many places an almost complete protection against the action of the waves. In favored localities the algæ creep up nearly to the limit of high tide. Marine plants fasten themselves merely to the surface of the rocks; while land plants extend their roots down into the crevices, and thus, while protecting the surface, nevertheless aid in the breaking up of the rocks.

From your own observations describe the protective influence of vegetation along ocean, lake, or river bank.

Effect of Rock Structure upon Coastal Cliffs. — When ocean cliffs consist of rock which does not disintegrate readily, the recession of the cliff will take place chiefly through the undermin-

Fig. 338.
York Harbor, Maine.

ing action of the waves (Fig. 12). Caverns and overhanging cliffs are formed, which finally lead to the sudden falling of large masses of rock. These fragments are attacked by the waves, and as soon as they are removed the waves again go at the work of undermining the cliffs.

Where the rocks crumble readily under the attack of the air, of moisture, of heat and cold, the cliff will probably slope back. In fact, there may be scarcely any cliff at all, for the waves in such a case rush up the slope, wearing it away from above (Fig. 339).

Mention some of the common rocks which would not be likely to afford vertical cliffs.

The position of the strata and the presence or absence of joint planes sometimes become of great importance in determining the slope of cliffs. Where the strata dip steeply toward the land, the cliffs may overhang, as in Fig. 340. If they dip seaward,

Fig. 339.

Rapid crumbling of the rock under atmospheric influence prevents the formation of a steep cliff. Coast of California.

the rock will be removed along the plane of stratification, and a smooth, even slope will be presented toward the water (Fig. 341).

Effect of Elevation of the Land. — The continual but slow movements of the earth's crust naturally result in a shifting of the coast line. If the land is rising, the shore will be pushed seaward; if it is sinking, the water will creep over the bordering lowlands.

If both the bed of the ocean and the land lying back of a given shore have long, gentle slopes, a movement, either up or down, of no more than ten feet, will have an important effect in

shifting the shore line; but if the slopes are steep, a change of level of hundreds of feet will affect it but little.

What portion of the coast of the United States is bordered by mountains? Trace out those portions of the coast where a slight sinking of the earth's crust would force the water far over the present land.

FIG. 340.

The strata dip steeply landward, and give an overhanging cliff. Near Port Harford, California.

Review what has already been said with reference to the contrast in appearance between the bed of the ocean and the land surface. Impress this difference more firmly upon your mind by a study of several Coast Survey charts upon which the soundings are given.

The plain-like surface so characteristic of sea floors has been formed through the combined action of the waves and the sediments which have collected upon it. Wherever resistant rocks occur, there will be rocky points or reefs. After an uplift of the land these will rise from the old sea floor as picturesque rocky crags. Such elevations are known as *rock stacks*. The one shown

Fig. 341.

The rock strata dip seaward, and as they wear away give a retreating cliff. Near Gaviote, California.

in Fig. 342 is remarkably precipitous, and is composed of a lenticular mass of jasper inclosed in rocks easily worn away.

Describe the character of a marginal land surface recently raised from beneath the ocean. Describe the character of the marginal land where there has been a subsidence. Why is the coast of Maine so much more broken than that of the South Atlantic States, since the whole coast has recently undergone subsidence? The coast of California has also sunk several hundred feet in recent times. Can you explain why there are so few good harbors along this coast? Examine the position of the mountains, and you may gain some help in answering this question.

The movements of the earth's crust are interrupted by periods of rest, and at every such period the waves cut a new cliff. Where the land is rising there is formed, then, a series of steps, or *terraces*. These consist of an alternation of steep and gentle slopes, the former being the cliffs against which the waves used

FIG. 342.

Rock stack rising from a coastal plain. Coast of central California.

to beat, and the latter, portions of the sea floor at successive periods.

The most remarkable terraces upon any of the coasts of the United States are found upon the islands and the ocean slopes of the Coast Ranges of California. San Clemente Island is particularly noted for its terraces, of which there are eighteen, ranging in elevation from twelve to fifteen hundred feet above sea level.

San Pedro Hill, situated upon the coast west of Los Angeles and rising to a height of fourteen hundred feet, is marked by twelve terraces, of which several appear in Fig. 343. Upon the coast of northwestern California there is a remarkably interesting remnant of a terrace having an elevation of seven hundred feet (Fig. 344). A little north of San Francisco there is a well-marked wave-cut terrace having an elevation of fifteen hundred feet (Fig. 345) above the sea. The presence of a recognizable terrace at such a height particularly impresses us with the magnitude of the changes that have taken place upon the earth's surface. When the waves cut this terrace, California must have been broken up into islands and sounds, and must have possessed none of the fertile bottom lands for which it is now noted.

FIG. 343.

Wave-cut terraces at Point San Pedro, California.

Trace out in a general way what would remain of the land east of the Rocky Mountains if it also had been submerged to the degree that California was.

Effect of Submergence of the Coast. — The last sinking of New England, with its hilly and mountainous surface, gave rise to innumerable bays, islands, and channels.

With the aid of several of the topographic sheets of the Geological Survey, such as Boothbay, Bath, Gray, and Casco Bay, Maine, study carefully the relation of the bays and inlets to the present streams, and state all the reasons for believing that this is a sunken coast.

FIG. 344.

Remnant of a wave-cut terrace, having an elevation of 700 feet. Coast of Northern California.

The sinking of the land upon the north Pacific coast has led to the formation of features similar to those of New England, but upon a much larger and grander scale. Fiords, at the mouths of which the water is sometimes nearly one thousand feet deep, mark ancient river valleys which received their final shaping at the hands of the glaciers. Along the California coast the land has in recent years sunk about three hundred feet.

Compare the position and regularity of the mountains along the California coast with those of Alaska, to find out the reason for the absence of many harbors upon the former. Using the large contour map of the United States published by the Geological Survey, trace out the coast line which California would possess if the land should sink five hundred feet. Describe the origin of Puget Sound. What has made the Columbia River navigable for ocean vessels up to a point near Portland?

FIG. 345.

Wave-cut terrace near Fort Ross, north of San Francisco: 1500 feet above present level of the ocean.

Give reasons for the fact that no bar obstructing navigation has been formed across the mouth of San Francisco Bay.

The Oceanside, California, sheet presents exceptionally interesting features due to coastal movements and stream action. Note the dissected coastal plain, the lagoons in the submerged and silted-up valleys, the barrier beaches, and the deflected stream mouths.

The Formation of Islands. — Islands are frequently produced during the wearing away of the coast. They represent either portions of the solid rock less easily destroyed, or hills once rising

from a coastal plain. Such islands are small, and after a time are reduced to mere reefs (Fig. 351).

The larger coastal islands are the result of the subsidence of hilly or mountainous land. Such is the origin of most of the islands along both the Atlantic and the Pacific coasts of North America. The Santa Barbara Islands, lying off the coast of

FIG. 346.

A remarkably perfect wave-cut terrace and cave, now 10 feet above the level of the ocean. Near Port Harford, California.

California, form parts of one mountain range which has been submerged until it is separated from the mainland. These islands rise from a submarine plateau which forms a part of the continental mass.

What are oceanic islands? Mention a number of them and give your reasons for considering them as such. Of what material are oceanic islands formed? Continental islands described in the previous paragraph are formed of rocks similar to those upon the adjoining mainland. Find out what you can about the depth of the sea surrounding oceanic islands. To which class do coral islands belong? To which

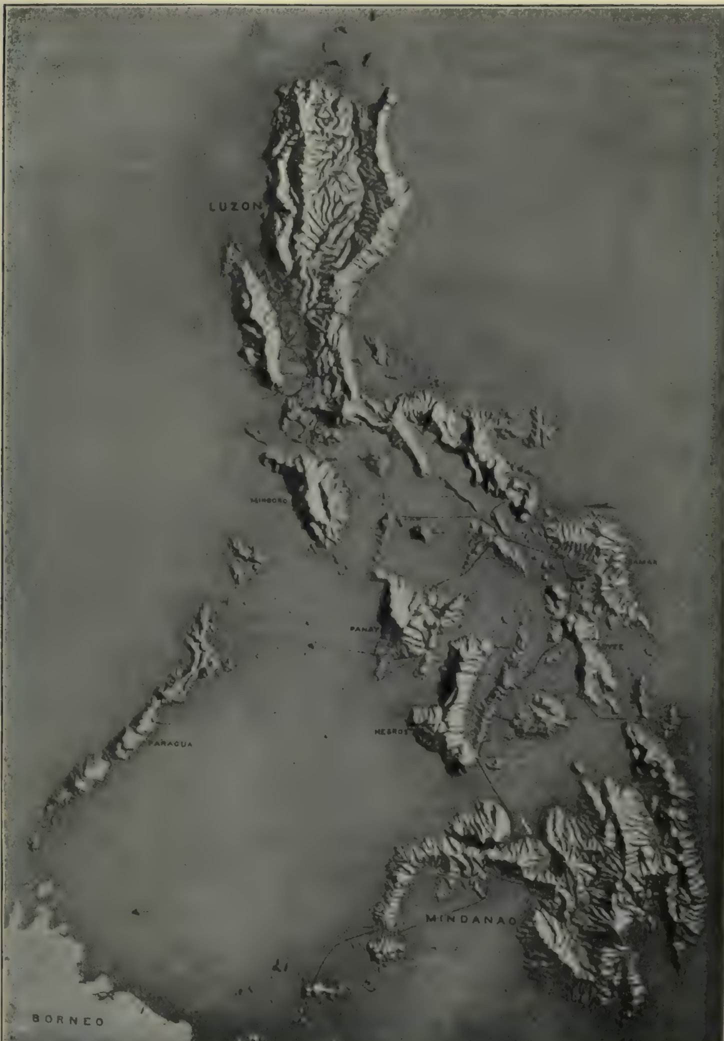

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FIG. 347.

Effect of partial submergence of a mountainous land.

(From a relief model of Philippine Islands, constructed under direction of Gen. A. W. Greely.)

class do the West Indies, Madagascar, and New Zealand belong? Do these all rise from the continental platform?

The Life of the Shore Line. — We are accustomed to think of the shore as a line sharply dividing the life of the land from that of the sea; but this is not exactly true, for many organisms go back and forth between the land and the water.

FIG. 348.
Islands formed by the sinking of a hilly land, at the entrance to Esquimalt Harbor, Vancouver Island.

Few sea plants have adapted themselves to the land, but many land plants have become used to the shallows and brackish water of the lagoons of the sea. The sea grasses are true grasses, which have become so adapted to salt water that they can live in no other. Upon the coastal flats and dunes, which are always more or less impregnated with salt, there are many land plants that will not thrive elsewhere.

Whales, seals, and walruses were originally land animals, and some species of birds are more at home in the water than upon the land.

Find out what you can about the structure of whales and seals, and tell how we know they were once dwellers upon the land.

Certain sea animals have become accustomed to fresh water and even to a life upon the land. The salmon spends a part of its life in fresh water, going there to spawn. Crabs and molluscs come out upon the land, and the latter have in many cases become adapted to a permanent life there.

FIG. 349.

Looking west from the Berkeley Hills, across the northern arm of San Francisco Bay. This bay occupies a drowned river valley.

The greatest variety of sea life is found between high tide and a few fathoms below low tide. The varied conditions in this zone lead to an abundance as well as diversity of life.

The character of the shore and the adjoining ocean bottom has an important influence upon the distribution of life. The rocky bottom, the sandy bottom, and the muddy bottom are each distinguished by different organisms. Life among the rocks is most varied, for here many forms that need a firm bottom upon which to fasten themselves can make their homes. Others

find protection in the hollows of the rocks and among the seaweeds. The poorest places for living things are the sandy and pebbly shores, where the material of the bottom is constantly shifting.

The Influence of the Coast upon Life. — The coast line, with the shallow water along it, is an important factor in the spread

Fig. 350.

A sea cliff abandoned by the waves, as a result of a slight uplift of the land, near San Juan Capistrano, California. The Sante Fé Railroad has taken advantage of the easy route offered, on its way to San Diego.

of animals and plants. Many sea organisms cannot live in deep water and consequently can spread only along a continuous shore. Closely related forms of this class have been found in parts of the world far apart and now separated by deep ocean waters. Upon the different continents there are also land animals which must have descended from the same stock, though now they are separated by broad bodies of water. We know that the land is never stationary for any great length of time, and the most reasonable explanation of these facts is that a former land con-

nection existed between Asia and America, and America and Europe.

Point out the probable location of this connection.

What can you say about the possibility of ocean currents transporting the seeds of plants to a great distance? Where would you expect a piece of wood dropped into the ocean east of Florida to be carried?

FIG. 351.

Flat-topped islands cut out of a coastal plain through the action of the waves. Coast of Northern California.

Find out what you can about the life of Australia. What peculiarities do its animals exhibit which indicate that it has been a very long time since this land was connected with Asia?

How do you suppose that the native plants and animals of the Hawaiian islands reached their present home? Are there any large native wild animals upon these islands? What is the relative depth of the ocean about the islands?

The climate of a coastal region where the prevailing winds blow from the water is so much modified as to have an important influence upon life. The western coast of North America has a climate which is much tempered in this manner. The average

summer temperature of San Francisco is but little higher than that of winter, while a temperate climate is enjoyed as far north as Sitka. This makes it possible for the same species to range through a much greater latitude than is ordinarily the case.

Compare the climatic conditions of the west coast of Europe with those of the west coast of America. Tell what you can about the

Fig. 352.

Morro Rock, coast of central California. Island of resistant igneous rock, rising from a submerged coastal plain.

climatic influence which the Atlantic exerts upon the eastern coast of North America.

Coast lines offer favorable and easy conditions for the spread of people, particularly if the shores are broken and more or less protected by islands. An irregular coast well supplied with harbors encourages a life upon the sea. This leads to trade and commerce with other people. Life upon the sea tends to the

FIG. 353.

A shore line productive of a rich and varied marine life. Carmelo Point and Bay, coast of California.

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FIG. 354.

Tucker's Wharf, Marblehead, Massachusetts.

development of strong and resolute character in the struggle with the storms, while the interchange of products between different peoples aids the progress of each in civilization.

What can you say as to the effect which many islands and shoals along a coast have upon the fishing industry? In what part of our country does this industry employ the greatest number of people?

FIG. 355.

The fiord region of British Columbia: showing a sunken coast.

The coast of New England is more broken and better supplied with harbors than any other portion of the United States, and here foreign commerce and whaling became prominent at an early date. What effect had this familiarity with the sea upon the results of the War of 1812? Mention different nations which appear to have been influenced in their development, not only by their situation with reference to the sea, but also by the particular character of their coast lines.

The Pacific coast Indians living north of Puget Sound travel almost exclusively by water, for the coast is deeply indented and bordered by islands; but south of the mouth of the Columbia

River they rarely venture upon the waters of the ocean. These northern Indians have become very expert in the making and handling of canoes. The Indians living along the unprotected coasts of California travel by land or upon the rivers.

The presence of few harbors upon the Pacific coast south of Puget Sound delayed for a long time its exploration and settlement. The prevailing winds, being from the northwest, were also against the expeditions which tried to make their way up the coast from Mexico.

From what we have learned it can now be seen how necessary for the development of our country was the last subsidence of its coasts. Without the magnificent harbors at the mouths of the leading rivers, we never could have attained our present prominence as a commercial nation.

Is a nation likely to advance rapidly whose coast is without safe and commodious harbors and whose main settlements are shut off from the sea by mountains? What is the influence of unhealthy coastal lowlands upon the development of a country? Give some examples illustrating the last question.

CHAPTER XVIII.

THE OCEAN.

Introduction. — The ocean now covers about three-fourths of the earth, but far back in its history the proportion of water surface is believed to have been still greater. If the theory that long ago the mountains were not as high and the ocean basins not as deep as they are at present is a correct one, it can be readily understood that the water must have been more shallow and consequently covered a greater area.

Another reason for believing that the water surface is less now than formerly is that as the crust of the earth has gone on thickening, more and more of the water has been absorbed into it. The interior heat at first would have kept the water largely upon the outside; but with the cooling of the surface, the water has continued to creep into the pores and fissures of the rocks, and to unite chemically with many of their mineral constituents. Serpentine, a common rock in many parts of the earth, contains about thirteen per cent of water. Taking into account all the water, including that in the air as well as that absorbed into the rocks, it has been estimated that only about one-half remains upon the surface of the earth at the present time. If all the water were in the ocean, little land would appear above its surface.

Using any available source, compare the average elevation of the land with the average depth of the ocean. If the land were planed off to the level of the present ocean and the waste dumped into the water, how much would the surface of the water be raised? Describe in a general way the effect upon the different continents of an increase of water sufficient to make the depth one thousand feet greater than it is at present.

The earth is not a perfect sphere, but is slightly flattened at the poles. How much is this flattening, and in what manner was it brought about? In answering the latter question, remember that the earth is believed to have cooled down from a molten condition. Compare the effect of rapid rotation upon the particles of mud attached to the outer rim and to the hub of a wheel. Where is the tendency to fly off the greatest?

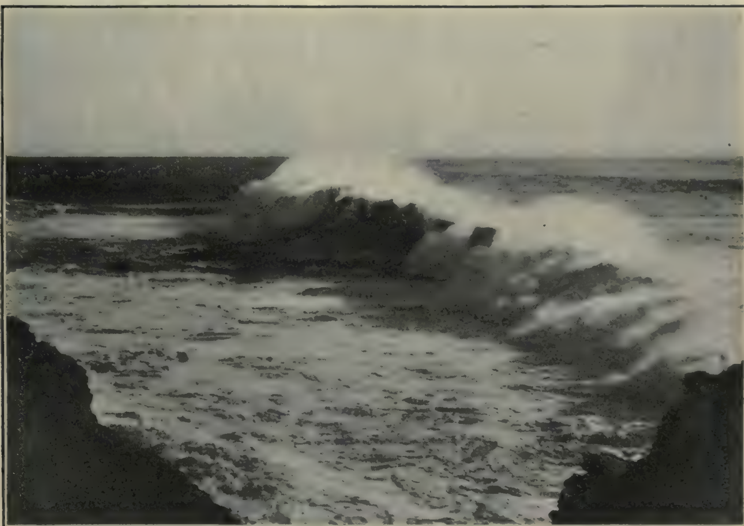

FIG. 356.

A storm wave breaking as it approaches the shore.

Does the rotation of the earth have any tendency to heap up the water toward the equator? Under what conditions would the surface of the water envelope of the earth assume the form of a perfect sphere? Mention the different agents which disturb the water and prevent the formation of a perfectly spherical surface.

Ocean Basins. — Our studies have shown that nearly all portions of the earth, now dry land, have at different times been submerged beneath the ocean. This fact, however, must not lead us to think that the ocean bed and the continental elevations have ever completely changed places. The deep ocean basins

FIG. 357.

Relief map of a portion of the Pacific coast of the United States: showing the steep outer border of the continental plateau.

have probably always been occupied by water since the earth cooled off sufficiently for it to stand upon the surface; while the continental elevations have been periodically overflowed as the land rose and sank.

Sum up all the evidence you can obtain to prove that the present land has at some time been beneath the ocean. What portions of our continent are believed to have been dry land the longest?

Oceanic islands contain no such sedimentary rocks as conglomerate, sandstone, and shale, with their fossil remains.

What does this fact indicate as to the origin and history of such islands, and of the deep basins from which they rise?

Prepare a profile sketch, showing the continent of North America and the basins of the Atlantic and Pacific Oceans. Note how small is the cross-section area above the water compared with that below.

In what part of the ocean basins are the greatest depths? Compare them with the greatest heights of land. These hollows of the ocean basins are not confined to limited areas, like the lofty mountain peaks which project above the earth, but are of great extent.

The Continental Plateaus. — The continental elevations, or plateaus, are in most places (Fig. 357) sharply set off from the ocean basins; but the shore rarely marks this line, for the excess of water often submerges, as in the above example, the borders of the plateaus. During the oscillations of the land, the shore of the ocean may at one period coincide with the border of a continental plateau, and at another the water may sweep far over its lowlands. Where high mountains border the continent, this migration of the shore line back and forth is not noticeable. The formation of a mountain range may take place without any general continental change of level, and this will also greatly modify the shore line.

Note, upon a relief map of North America and the adjacent ocean depths, the submarine bench or plateau upon both the eastern and western borders. Using the Coast Survey charts of the ocean floor off San Francisco and south of New York, prepare sketches showing the slope of the adjoining land, the width and slope of the submarine plateau, and its steep outer edge extending down to the bottom of the ocean basins.

The submarine plateau is scarcely noticeable for a distance along the middle portion of the California coast. Here, opposite the Santa Lucia Range, which rises to a height of four thousand feet close to the shore, the ocean has a depth of six thousand feet only fifteen miles from the land.

From any available source, prepare a cross-section sketch through the highest point of the Hawaiian Islands, showing their submarine

slope and the relative depth of the ocean floor upon which stands the pile of volcanic material forming the islands.

State all the facts going to show that both the eastern and western coasts of North America are now submerged more than they once were.

Soundings show that the Hudson River and other streams of the Atlantic slope have submerged channels extending across the submarine continental shelf to the borders of deep water. Upon the Pacific coast there are also submerged channels extending down to a depth of more than two thousand feet.

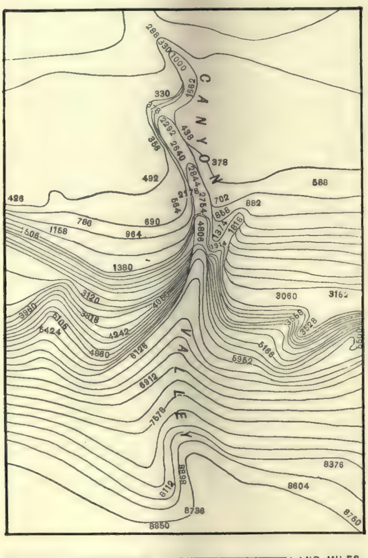

FIG. 358.

Contour map of the drowned Hudson canyon, extending seaward, from 93 miles off Sandy Hook.
(Dr. J. W. Spencer.)

Find out all you can from the Coast Survey charts of the submarine valley in Monterey Bay, California. Make a careful study of the submarine canyon of the Hudson River, which is believed to extend downward across the continental shelf to a depth of more than a mile (Fig. 358).

The islands along the California coast all rise from the undulating surface of the submerged portion of the continental plateau, which varies in width from ten to one hundred and fifty miles. Upon one of the Santa Barbara Islands, which would be connected again with the mainland should the land rise one thousand feet, there are bones of such animals as the horse and mastodon, which inhabited California about the time of the Glacial period.

Character of Ocean Water. — Ever since water first condensed upon the surface of our earth, it has been collecting the soluble

minerals from the decaying rocks. Continually evaporating pure water and receiving the washings of the land in the returning streams, the ocean has been an important factor in the formation of many mineral deposits.

The following table gives the proportions of the most important substances in solution in sea water. All together they form about three and a half per cent of the weight of the water.

Chloride of sodium (common salt)	.75
Chloride of magnesium	.10
Sulphate of magnesium (Epsom salts)	.05
Sulphate of calcium (gypsum)	.04
Chloride of potassium	.04
Bromide of sodium	.01
Carbonate of calcium (the material of limestone)	.005
All other substances	.005
Total	1.000

About half the chemical elements, including gold, have been found in sea water, but most of them are in such small quantities that it is difficult to estimate them quantitatively. The proportion of lime, as can be seen from the table, is very small.

What mineral substance do we find most abundant in ordinary stream water? How would you account for the marked difference in composition between the water of the sea and the water of the streams that enter it?

Of what mineral substance are the skeletons of most organisms formed? What is the composition of coral? of shells? What is the source of the material forming these hard parts of sea plants and animals?

Explain what you have already learned about the origin of beds of limestone, which are sometimes several thousand feet thick. What animal remains found in limestone show us how the rock was formed?

While common salt is not taken out of the ocean water in the same manner as is the lime which is built into the coral reefs, the shells of molluscs, the bones of fish, the skeletons of foraminifera, etc., yet it, too, has been concentrated in beds of great

thickness and extent. The evaporation of water in a lagoon into which the ocean occasionally breaks will result finally in a bed of salt. The drying up of an arm of the ocean which has been cut off through some movement of the land will also produce a deposit of salt. With the salt beds thus formed, there are almost always associated layers of gypsum, which is another of the minerals present in sea water.

Explain how you would separate pure salt from the other substances which sea water contains? In this connection review what was said upon this topic in the chapter on lakes.

Another of the elements present in sea water in very small amount is silica; but as there is an important group of microscopic organisms known as diatoms which build skeletons of silica, this mineral has collected at various times upon the bottom of the ocean in beds hundreds of feet thick. Diatomaceous earth and jasper are two forms of silica which have originated in this manner.

Still another of the rare elements in sea water is iodine, which is present in certain seaweeds in quantity sufficient to be commercially valuable.

Describe how iodine is obtained from seaweeds.

Is the saltness of the ocean the same in all parts? What is the influence of large rivers upon the ocean about their mouths? Compare the saltness of the ocean where it rains a great deal, with those regions where there is little rain and evaporation is rapid.

Show by floating an object upon fresh water and then upon salt water which is the denser.

The Floor of the Ocean. — Judging from all that we can learn of the floor of the ocean, both from the character of uplifted lands and by means of soundings, it consists of vast, monotonous plains, occasionally broken by ridges and steep mountain peaks.

Beginning with the boulders and pebbles upon an exposed beach where the water is in violent motion, describe the change in the character of the accumulating sediments as we follow them into the deeper

and more quiet water. Note the character of the bottom as given for different soundings upon the Coast Survey charts. Will the sediments accumulate more rapidly where the currents are strong or gentle, near the shore or far removed from it?

Find out what you can about the dredge, an apparatus constructed for the purpose of obtaining samples of the bottom of the ocean and of the life existing there.

The fine, muddy silt from the land is rarely carried by the currents more than two hundred miles out to sea, and it would be natural to suppose that all sediments are absent from the deeper and more remote portions. The dredge has shown, however, that this is not the fact. Sediments are accumulating in the lowest depths, but they do not come from the land. The reddish and grayish clays found at great depths are shown by the microscope to be made up largely of volcanic ashes. During volcanic eruptions this dust is distributed far and wide before it settles to the earth. The ashes from the eruption of Krakatoa (p. 435) were carried in the upper atmosphere entirely around the world.

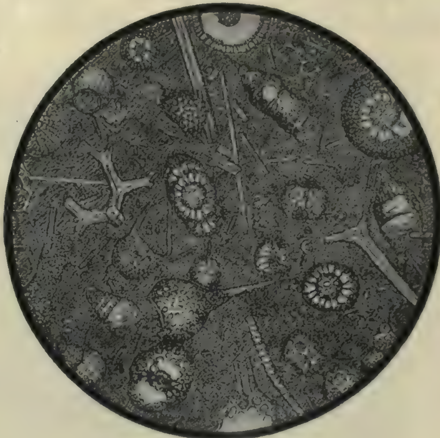

FIG. 359.

Radiolarian ooze, dredged up by the *Challenger* expedition, from a depth of 4475 fathoms, in Lat. 11° 24′ N., Long. 143° 10′ E. Magnified one hundred diameters. This is from the deepest abyss whence organisms have yet been obtained.

Everywhere, except in the very deepest parts of the ocean, where red clays alone are found, the soft sediments of the bottom, known as *ooze*, contain remains of organisms of various kinds.

The surface waters of the ocean are filled with a multitude of living things, a large part of them microscopic in size, but having in many cases skeletons which are not dissolved in the water when the organisms die. These hard parts finally settle to the bottom and aid in forming the ooze (Fig. 359).

Movements of the Water. — Except in the greatest depths, the waters of the ocean are in constant motion, although in most cases

FIG. 360.

United States steamer *Wateree*, stranded one-fourth of a mile inland, by a tidal wave, upon the coast of Chili in 1869.

this movement is extremely slow. These motions are the result of the winds, of differences in temperature and density, and of the tidal attraction of the sun and moon.

Study carefully the movement of the waves upon any convenient body of water. Drop a small piece of wood upon the water and note whether it moves with the waves or not. If there is any movement at all, what is its direction with reference to the wind? How do the waves behave as they approach shallow water? What is the cause of the

"white caps"? Explain what is meant by the "undertow." Compare the movement of waves upon water with that of waves upon a meadow or field of grain when the wind is blowing.

What can you say as to the persistency of water waves? What is the meaning of heavy swells when no storm has occurred near the observer? Find out what you can about the height of storm waves and the depth to which they affect the water. Give illustrations of the force with which waves strike objects in their path. What is the effect of placing oil upon the water during a storm? What causes waves?

Earthquake waves caused by some disturbance beneath the ocean have frequently wrought great destruction to people and buildings. At such a time the water usually retreats and then rushes back with violence, sweeping far over the land if the shore is low (Fig. 360). The eruption in 1883 of the volcanic island of Krakatoa, one of the East Indies, formed waves which were felt halfway around the world (Fig. 361).

Fig. 361.

The destruction of fishing boats during the eruption of Krakatoa.

The Tides. — The rise and fall of the water along the shore of the ocean twice every day cannot fail to interest every one who visits the seashore. The apparent connection between the movement of the tide and the position of the sun and moon was noticed long before any reason could be given for it.

Mention and describe the three movements of the ocean water.

Every particle of matter attracts every other particle. The larger the body, if the distance and density remain the same, the more it attracts other bodies. The earth attracts the moon and holds it in its path, and the moon in turn attracts the earth, but being much smaller does not have a great effect upon the earth's

Fig. 362.

High tide at Wolfville, near the mouth of the Gaspereaux River, Nova Scotia.

movement. The solid earth does not yield noticeably to the pull of the moon; but the water upon its surface, being free to move, is affected. It is heaped up upon the side nearest the moon, because there the pull of the latter is strongest; while a corresponding rise in the water takes place upon the side farthest away, where the pull is weakest.

As the tides are held in the same position with reference to the moon, they sweep around the earth as it turns upon its axis from west to east.

If the moon always held relatively the same position with reference to the earth, what would be the time between two successive high tides? What is the period of revolution of the moon around the earth, and why does it appear upon the horizon a little later every day? How much do the tides lag behind, each day? What is the effect upon the tide when the sun and the moon are nearly or quite in the same line with the earth? What

Fig. 363.
Low tide at Wolfville, near the mouth of the Gaspereaux River, Nova Scotia.

are *spring* tides, and how often do they occur? In what position are the sun and moon with reference to the earth at the time of *neap* tides?

Upon the open ocean, the rise and fall of the tide is much less than one would suppose, being scarcely more than two feet. Among the islands and channels of British Columbia and the Alaskan coast, the tides rush with such violence that frequently large steamers are obliged to wait for the flood or ebb, when the water becomes more quiet. In some bays the incoming tide assumes the form of a wave, which is known as the *bore*.

In what way do the land masses and the channels between them augment the height and force of the tides? Find out what you can about the high tides in the Bay of Fundy (Figs. 362, 363) and the danger of being caught out upon the sands by the incoming tide. Compare the tides in a long V-shaped bay with those in one that broadens from a narrow opening. Which will afford high tides and swift currents, and which a very moderate rise and fall of the water?

Are the tides confined to the ocean or are they noticeable upon large lakes? If your home is near the ocean, study in detail the movements of the tide. How much does it lag behind the moon? What is the amount of rise and fall of the water? What is the effect of a heavy storm at the time of spring tides? Do the movements of the tides affect the coming and going of vessels, or have any other influence upon people and their industries?

Ocean Currents. — There are other important movements of the ocean waters besides those of the tide. The latter are periodic, but these we are now going to talk about vary but little through the year, either in course or strength.

Mention the different factors already referred to which determine the currents of the ocean. Satisfy yourself from personal observation that a current is started upon a pond or lake in the direction in which the wind is blowing. Is such a current deep or shallow?

Lake Erie lies parallel to the course of the prevailing storm winds, and at times a strong surface current is set up in the direction of the outlet. In this manner the water is sometimes heaped up at Buffalo six or eight feet.

In the region of the equator the prevailing winds blow toward the west and thus establish a steady movement of the water in that direction.

Show, upon a chart of the ocean currents (Fig. 364), the connection between this westward movement, or *drift*, and the Gulf Stream. Find out all you can about the Gulf Stream. What is its width and velocity east of Florida? What is the difference in temperature between this stream of warm water and the bank of cold water off New England? What are the farthest points reached by this northeasterly moving current? What is the Sargasso Sea, and what are the conditions which give rise to it?

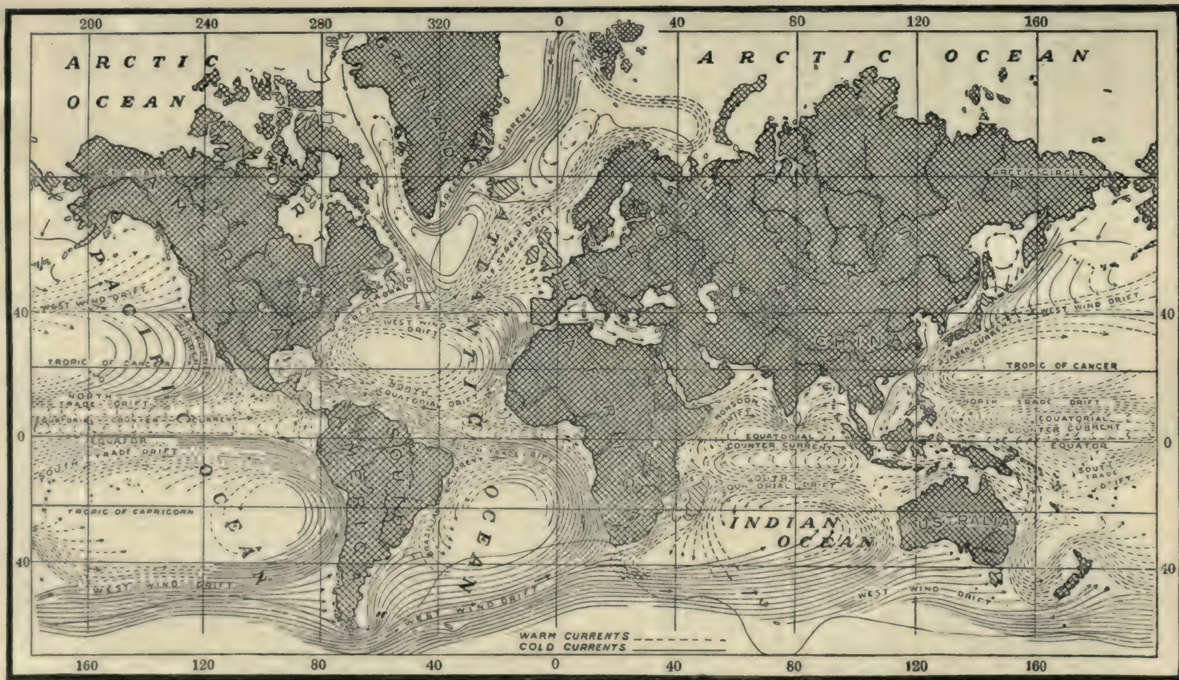

Fig. 364.

Map of the ocean currents.

p. 439

Trace out the course of the Japan current. What is the reason that ships sailing west around Cape Horn encounter such difficulties? What peculiar climatic conditions are brought about by the southward moving Labrador current where it comes in contact with the Gulf Stream?

What can you say as to the reasons for the extremely mild climate of western North America and western Europe in high latitudes? It has been thought that this mildness was directly due to the nearness of the warm currents referred to above, but is this view a correct one? Can the water itself warm the land back of the immediate shore line? From any personal observations, show the influence of water upon the temperature of the air passing over it. What is the direction of the prevailing winds in the North Pacific and North Atlantic Oceans? In the temperate latitudes, which is colder in winter, the land or the water? The coast of Labrador is bordered by the cold Labrador current; is this the reason that northeastern America has such cold winters? What kind of a climate would be possessed by the eastern United States if the prevailing winds blew from the Atlantic? Explain fully the real effect of ocean currents upon the climate of adjoining lands.

Find out all that you can about the influence of the ocean drifts, or currents, upon the courses pursued by ships. Are the main lines of ocean travel determined to any important extent by the position and direction of the currents? What frequently happens to sailing ships caught in some strong current?

What is the effect upon the size of a body when its temperature is raised? Is its density increased or decreased by such a process? Where do you find the coldest air at night — in the bottom of a valley or upon the slopes above? State, from your observation of a pond or lake, whether the water near the bottom is warmer or colder than that upon the surface, and give your reasons.

By the addition of some coloring matter to the water of a jar which is being heated at the bottom, note the circulation which is set up.

The unequal heating of ocean waters from the sun's rays has an important influence upon the ocean circulation. The cold water of the polar regions moves slowly downward into the abyssal depths in the temperate and tropic latitudes, displacing the warmer water, which is forced upward toward the surface. There it joins the great currents, which finally carry it back toward the poles to be cooled again.

The movement of the cold water from the poles is known to

be a fact, because in the case of such basins as the Mediterranean Sea and the Gulf of Mexico, which are shut off from the open ocean by elevated barriers, the water at the bottom is very much warmer than at the same depth in the ocean. In the bottom of the ocean the water has a temperature but a few degrees above freezing; while in the Gulf of Mexico, after a moderate depth is attained, the temperature remains almost constant until the bottom is reached.

The Temperature of the Ocean. — The abyssal depths are extremely cold, as we have already seen, and exhibit a constant degree of temperature throughout the year. In the polar regions the water upon the surface in summer is but little above freezing, and in winter the temperature becomes low enough to permit the formation of vast ice fields many feet in thickness.

What is the temperature required to freeze salt water as compared with fresh? What are "ice floes"? State the source of icebergs. What proportion of a berg floats above the surface? Why is ice lighter than water? Do bodies usually become larger upon changing from a liquid to a solid state? What would happen if ice were heavier than water? What is the effect of wind and currents upon ice floes?

Where do icebergs reach farthest south in the Atlantic? Find out what you can about the extent and character of the ice in the Antarctic Ocean.

Importance of the Circulation. — The circulation of the ocean water is of the highest importance. If there were no circulation, the waters of the polar regions would become so cold that the ice would extend much farther toward the temperate latitudes than it does at present; while in the tropics the surface of the water would be almost too warm for the existence of life. The movement of the ocean water results in a continued mixing of the hot and cold portions, just as the circulation of the air reduces the extremes of temperature which would otherwise make much of the earth's surface uninhabitable.

The ocean currents aid in the distribution of life, for a large portion of the organisms inhabiting salt water float passively in

it, having little, if any, power of locomotion. The equalizing of the temperature by means of the currents also permits the same species to range over a much wider area than would otherwise be possible.

Another important result of the circulation is the transference of the surface waters to great depths, for they carry with them carbonic acid and oxygen and thus make it possible for organisms to inhabit abyssal portions of the ocean.

State any observations which you have made as to the necessity for supplying fish with aërated water, — that is, water which has air disseminated through it. Plants grown in an aquarium with fish will give off the oxygen necessary for them.

The Life of the Ocean. — Living things are much more abundant and varied in salt water than in fresh water. The shallow portion of the ocean probably first offered conditions for the existence of life upon the earth, and it spread from here to the deep water on the one hand, and on the other, to the fresh water and the land.

The continually moving currents, the variation in temperature and saltness, and the abundance of food supplies have produced along the shore and in the shallows the remarkable variety of living things which meets one's eyes upon a visit to the seashore.

The animals of the land, with the exception of some parasites, are free to move; the plants are mostly fixed in one place. In the ocean, the organisms either swim, going where they please, float with the currents, or are attached to the bottom. Many are free during the earlier part of their lives, but become fixed at a later period.

What can you say as to the source of the food of the marine plants? How are they held in place? Have they any true roots? Of what advantage are the currents to those organisms which are fixed in one place?

Just as on the land we distinguish different zones of life in ascending a mountain, so in descending to the depths of the ocean we pass different zones, in each of which are organisms adapted to a certain amount of pressure, temperature, and light.

What is the effect of bringing fish rapidly from a great depth to the surface? Why is the depth to which divers can go so limited? What is the effect frequently produced upon people going from the sea level up a high mountain?

Many organisms are so constructed that they can pass from one ocean level to another, while others are strictly confined to certain narrow limits.

As we descend in the ocean, light becomes rapidly fainter, and at about twelve hundred feet there is not the least glimmer remaining. Below this there are depths covering more than half of the surface of the globe, where the bottom is one vast desert of slimy ooze. Here no vegetation exists, and only strange and fantastic animal forms are found.

Animals living below the reach of the sunlight are supplied with a faint phosphorescent light which enables them to see a little. There are vast hordes of low organisms which need light, but cannot stand the bright sun. During the daytime they sink far down in the water, but at night the surface of the ocean swarms with them.

The life conditions of the ocean are very different from those of the land. Upon the latter there are great variations in temperature between the different seasons, as well as between day and night. The temperature of the air and the direct heat from the sun, varying with the passing seasons, affect the water to a certain depth; but below about twelve hundred feet it always remains the same.

This unchangeableness of the deep ocean floor has permitted the preservation there of many animal forms from very remote times in the history of the earth, with their characters but

slightly modified. In these quiet depths organisms live on, unaware of the great changes which take place upon the surface.

Lands rise and sink; climate, shore lines, and ocean currents are modified; and with the ever new conditions the plants and animals both of the land and of the ocean shallows cannot remain fixed. Some will migrate and give place to others better adapted to the new conditions; some will become modified to suit the new conditions; while others will be killed off.

We have already learned of the part played by the inhabitants of the ocean in the making of materials useful in the industries (p. 109). Corals, foraminifera, echinoderms, molluscs, and fishes have furnished limestone and are the chief source of petroleum.

The diatoms (microscopic plants), sponges, and radiolaria have silicious skeletons and have formed thick beds of jasper and diatomaceous earth. Diatoms also live in fresh water; and in some of the beds of ancient lakes in the West are found the white deposits of their skeletons.

Many of the living animals of the ocean are sought for because of the products which they furnish. Mention a number of these.

CHAPTER XIX.

THE AIR.

Different Forms of Matter. — Every substance with which we are acquainted occurs in one of three possible forms. It is either a solid, a liquid, or a gas. Now let us review some of the properties of substances in each of these forms.

Mention substances that retain their shape if left to themselves. What ones need to be confined to be kept from spreading indefinitely through space? Give examples of substances which we can change from the solid to the liquid or gaseous forms. In which state do they require the most room? What do you mean when you say that a substance is brittle? malleable? hard? What do you mean when you say that it flows? Do substances usually occupy more or less space after they have been changed from the solid to the liquid form? What are the peculiarities of water in this regard?

What is the lightest gas, and for what purpose is it often used upon a large scale?

The particles of a gas act as though they repelled each other. Although invisible to us, they are believed to be in rapid motion, bounding and rebounding as they hit each other; and for this reason, when free to do so, they spread in every direction.

The more we compress a gas, the greater is the force needed to restrain it; for the little particles strike more frequently and with greater energy the walls which confine them.

Give illustrations of the force with which gas sometimes breaks its bounds.

In a solid, the particles are fastened firmly, each in the same position with reference to adjoining particles. When we liquefy a substance, the particles can change their position with reference to each other, taking the shape of the dish in which they are

placed. They are still attached to each other, but their coherence is less than before. When changed into a gas, the coherence has been lost and the particles spread indefinitely in every direction.

With a sufficiently high temperature every substance can be volatilized, or changed into a gas, as we commonly say. With sufficient cold and pressure those gases with which we are familiar may be liquefied and even solidified. It is in this way that liquid air has been produced.

All three forms of matter occur upon the earth at the present time, primarily because the temperature at which the different elements exist in the solid, liquid, or gaseous state varies widely, and secondarily because the actual temperature and pressure upon the earth lies between that necessary for the existence of some as gases and others as solids.

Give examples illustrating this fact. Upon what conditions is the temperature of the earth's surface dependent? If the temperature were a little lower, what would be the permanent condition of water? of mercury? What substances now solid would be liquid if the earth were much nearer the sun? Mention some of the minerals easily fused and volatilized.

The earth has cooled down until a solid crust has formed; while the interior, although still intensely hot, exists under such pressure that it behaves as though it were solid. The specific gravity of the interior of the earth is much greater than the surface, which is about two and a half times that of water. Next outside of the rock ball is the water, held by the pull of gravity in the hollows of its rough and broken surface, but not sufficient in amount to cover all of that surface. And finally, outside of all, is the layer of air, at the bottom of which we live. Thus we see the different earth constituents grouped concentrically, the heaviest at the center, the lightest upon the outside.

The solid earth and the liquid and gaseous envelopes are not separated by as sharp a line as we might at first think. Air and

water have been absorbed far into the crust of the earth, and the water envelope is constantly giving off vapor, which mingles with the air. The air, in addition, contains great quantities of solid dust particles.

Show by some simple experiments that the invisible substance which we call air fills all the space about us, presses upon us from all sides, and offers resistance to compression.

The Composition and Properties of the Air.—We want first to learn something about oxygen, the most important constituent of the air, — an element which is more abundant than any other entering into the composition of our earth, and one which is, at the same time, the support of all living things.

It is an exceedingly active element, for it seems, like some people, to take an interest in almost everything that goes on. It forms one-fifth of the air by volume, eight-ninths of water by weight, and one-third of the solid crust of the earth.

The oxygen in water and in the rocks is chemically combined with other elements; but in the air it is merely mixed mechanically with the other substances. Oxygen is present in the air as oxygen.

Illustrate further the difference between mechanical mixtures and chemical combinations.

Nitrogen, the other important constituent of the air, so dilutes the oxygen that the latter is less active. Organisms suited to the air as it is could not live long in pure oxygen, for their tissues would be burned up.

Besides oxygen and nitrogen, the air contains a varying amount of carbonic acid (carbon dioxide), argon, and vapor of water.

Place a piece of burning candle within a bottle inverted over a dish of water, and note whether or not it continues to burn long. What gas is necessary for the combustion to continue? What is the meaning of the fact that the water slowly rises in the bottle until the candle goes out?

You may wonder why it is that, if oxygen is so active, it should remain in the air and not combine with other substances. The fact is that the oxygen in the air does combine with other substances and is continually attacking and destroying many things with which it comes in contact. The rocks and minerals all about us are being destroyed by the action of oxygen, and their original constituents made over into others into which oxygen enters as a constituent.

What happens to wood when it is long exposed to the air? What has oxygen to do with the fire in your grate?

In many cases oxygen can attack substances only in the presence of moisture.

How is this shown by the formation of iron rust?

If the proportion of oxygen in the air decreases ever so little, the change has an effect upon the higher animals, making them less strong.

The carbonic acid in the atmosphere is largely supplied by decaying animal and vegetable tissues. Its amount varies at different times and in different places, because of the chemical changes that are constantly taking place.

What can you say about the air in cities? Where is the air purest? Mention the source of the dust particles which float in the air. What is the effect of falling rain upon the impurities in the air? When is the air most hazy and filled with impurities? What living things of microscopic size are found in the air?

The Pressure and Density of the Air. — Just as the animals of the deep sea have become so adapted to the great pressure existing there, that they are killed if brought to the surface, so the structure and organs of our bodies are adapted to the conditions at the bottom of the ocean of air in which we live. If the amount of oxygen in a given bulk of the air is lessened and the pressure decreases, as in going up a lofty mountain distress and sometimes sickness and death result.

Although we are not aware of it, the air presses upon us at the sea level with a force of about fifteen pounds to the square inch. Can you tell why we do not feel this pressure?

Show by a sketch the construction of the ordinary water pump, and explain how its use illustrates the pressure of the air. What is the height to which water can be lifted by such a pump? Will it lift water as high upon a mountain as at the sea level? Is there any difference in the boiling point of water at high altitudes and near the sea level? Why do mountaineers experience difficulty in cooking some kinds of food? What important feature of the atmosphere do these facts illustrate?

What is the range in elevation of those parts of the earth permanently inhabited by people?

The highest distance above the sea level that man has ever succeeded in reaching is about twenty-five thousand feet, and that was reached with the aid of a balloon. Mountains have been ascended to about twenty-three thousand feet. At this great elevation breathing becomes very difficult. Why is it necessary here to breathe more rapidly?

The top of the loftiest mountain (what is this mountain?) is probably beyond the power of man to reach. At this height fully two-thirds of the atmosphere has been passed, but that which remains stretches away into space for an unknown distance, ever becoming more rarefied.

How does the bursting of a balloon that has reached a great elevation illustrate the expansive power of the air and its rarity at that point? What can you say about the temperature at great altitudes?

Obtain a small glass tube about thirty-one inches long and closed at one end. Fill it with mercury and invert in a dish containing some of the same material. Explain why the mercury stands in the tube. What is the height of the column of mercury? This is the simplest form of the *barometer*, the standard instrument for determining the pressure of the air and, through this pressure, the elevation of any point upon the surface of the earth. What are the properties of mercury which peculiarly adapt it for use in the barometer and thermometer?

Observe the barometer for a number of days, noting whether the mercury remains at a constant height or not. What effect has the raising of the temperature of the air upon its density? Explain the prin-

ciple upon which the hot-air balloon is constructed. Carry on observations for a number of days, to determine whether the barometer changes in any regular way between the middle of the day and early morning, when the air is coolest. What is meant by the expression "the barometer is falling"? What does it indicate?

If the air were evenly heated over the earth's surface, its pressure would be practically the same at all points having the same elevation. In reality, however, some portions receive much more heat from the sun than do others, while the amount of heat reflected back into the air varies with the nature of the surface.

Does the air become warmer over the land or over the water, upon a summer day? What kind of a land surface reflects the most heat?

The unequal heating of the air causes it to vary in density and pressure. The warmer air expanding and thus becoming less dense is forced upward by the cooler, heavier air which moves in and takes its place. This starts currents in various directions.

What would be the effect of a downward current of air upon the barometer? What would be the effect of one moving upward?

It is necessary, then, in using the barometer, to take account of the temperature as well as of the nature of the air currents, when we wish to determine the elevation of a given place above the sea or the relative elevation of several places.

Locate upon a map of the United States the air pressures recorded in the table of the daily map of the Weather Bureau. Draw lines through all points where the pressure is the same. These lines are called *isobars*, meaning lines of equal pressure. Note the extreme range of high and low pressure. Note also the concentric arrangement of the lines about the areas of high and low pressure. The pressure given for each place is what it would be if that place were situated at sea level; for the elevations vary so greatly over the country that, unless the isobars are drawn for a uniform elevation, they would not have any meaning.

Temperature. — Our ideas of what is heat and what is cold are, in practical experience, merely relative. We speak of a substance as feeling warm or hot if its temperature is above that of our

bodies; and on the other hand, we say that it is cold if its temperature is much below that of our bodies.

The temperature under which life has developed upon the earth is intermediate between that of burning gases and that of frigid space through which the earth is moving.

Mention in degrees Fahrenheit the range in temperature within which we can live. To what extremes of temperature are some of the lower forms of life adapted?

While it is believed that our earth was once intensely hot, it has now cooled down to such a degree that the temperature upon the surface is due rather to the sun than to the heat radiating outward from the interior. If it were not for the sun, then, the surface of the earth would be almost as cold as space.

The distance to which the heat of the sun penetrates the solid earth is comparatively small. Below one hundred feet there is no change between winter and summer, and, in its stead, a slowly increasing temperature toward the center.

Mention a number of evidences of the internal heat of the earth.

In the mines of the Comstock Lode, Nevada, the quantities of hot and almost boiling water made mining below the three-thousand-foot level no longer possible. Hot water also gave much trouble in the Simplon tunnel. The Calumet and Hecla copper mines of northern Michigan are about a mile deep, but the rate of increase of temperature downward is there much slower.

Explain the construction of the thermometer and the difference between the graduation of the Fahrenheit and Centigrade scales. Give examples of the change caused in the size of bodies by altering their temperature. How is this principle illustrated in the thermometer? At what temperature does mercury freeze? In very cold regions, what is often used in thermometers as a substitute for mercury?

The part which the atmosphere plays in the retention of the heat received from the sun, as well as in its distribution and equalization, is fully as important as the heat itself. We might

compare this envelope about the earth to the packing placed around the boiler of an engine to prevent its heat from being lost.

It is thought that upon the moon there is little or no atmosphere. During the long days the surface becomes intensely heated (what is the length of the moon's day and night?), and at night, owing to the quick loss of this heat, the cold becomes extremely severe. It is not at all likely, then, that organisms adapted to the conditions on the earth could live upon the moon, although the moon receives upon a given surface about the same amount of heat from the sun as the earth would if it had no atmosphere.

Find out, if you can, what influence the atmosphere has in determining the total amount of heat which reaches the earth's crust.

How Substances are Warmed and Cooled.—Heat waves are moving out into the air in every direction, just as do the waves from a luminous body which give us the sensation of light. The dissemination of heat in this manner is known as *radiation.*

Place some convenient object, such as a flatiron, upon a hot surface and note what changes take place in its temperature. Where does it become warm first? Experiment with different objects, to see whether they all absorb heat at the same rate. Place the flatiron upon a cold surface and note the temperature which it finally reaches. Is the heat of the iron which is placed upon a cold body entirely lost through conduction? Place your hand near the iron while it is hot and describe what you feel.

The transference of heat or cold between bodies when in contact we call *conduction.*

If the iron is entirely removed from contact with any body and suspended in the air by a string, how is its heat mostly lost?

How will the temperatures of all bodies finally compare if they are left to themselves? If the heat radiated from the sun were shut off, how long do you think life could exist upon the earth?

How does the amount of radiant heat received from the sun in one year compare with that received in another? What would happen if each year the earth either lost or received more than it radiated? If

the earth's surface were all land, how would the rate of radiation compare with the present rate? If the surface were all water, what would happen in this regard? Explain the difference between temperature of night and day. Why is it coldest near morning? Why is the greatest heat in the afternoon rather than at noon, when the sun is the highest? Why do you find frost upon some bodies at night and not upon others?

The heating or cooling of liquids and gases by a mixing of their particles is *convection.* This is the most important means by which the temperature of liquids and gases is changed.

Apply heat to the bottom of a glass jar containing water and some easily floating sediment, and observe the currents established. Sketch and explain the air currents which are formed about a lighted candle or lamp. Illustrate the movement of the air about a fireplace, and explain the object in building a tall chimney.

Some bodies *absorb* heat readily and others *reflect* it.

Explain what is meant by this, using common examples. From what sort of bodies do you get the greatest reflection of heat? Will you be sunburned more in a country covered with vegetation or in a barren, rocky one? Which is cooler in summer, white or dark clothing of the same texture? Give reasons for your answers.

The Origin of Light and Color. — If you take a piece of iron and gradually increase its temperature, you will first begin to notice any change in it by feeling the heat radiating from its surface. As the iron becomes still hotter, there will come a faint glow, then a red, and finally a whitish, light. The ether vibrations which at first give us the sensation of heat have at last been so greatly increased in rapidity that they produce through the eyes the sensation of light.

Consult the Encyclopædia, under the word "Ether."

The light which comes to us from the sun is due to intensely heated and luminous vapors, and appears to us as white. It is not, however, a simple color, but is composed of a union of many.

With the aid of a glass prism through which a ray of sunlight is allowed to pass, you can show the composite character of this light. What colors do you see, and in what order are they arranged? Red,

yellow, and blue are known as the *primary colors.* How are these combined to produce orange, green, and purple or violet? Compare the succession of the colors in the rainbow with those produced by the prism.

The rays of light are *refracted* or bent in passing at an oblique angle from one clear substance into another of different density. Now, in the case of the prism, the different rays, which in the sunlight are combined, are each bent in a different degree, and so upon the screen we have them separated. The same refraction takes place when sunlight passes through raindrops and we see the rainbow.

Place a stick in an inclined position in a dish of water and note the apparent break in the stick at the surface of the water.

The different components of white light are not all reflected in the same proportion from the surface of bodies, and so we get the impression of various colors. Find out what is meant by the *absorption* of light.

What happens to the rays of light when they strike the surface of a mirror? What do we mean when we say that a surface is white? What do we mean by black? When a body appears red to us, what portions of the light are reflected and what portions absorbed?

Just as the rays of light are bent in passing from a rarer medium to a denser one, or *vice versa,* so they are bent in passing through air, which is denser in some places than in others. Upon deserts, and oceans as well, are seen those wonderful inverted pictures which always attract the attention. This phenomenon, called *mirage,* has lured to his death many a man, thinking that he saw in the distorted forms upon the desert horizon a body of water overhung with trees.

The various colors of the sky are due to the dust particles which are floating through all portions of the atmosphere. The particles break up the rays of light, reflecting and refracting them in all directions. It is these which give the impression of blueness to the clear sky; and at or near sunset the longer passage

of the rays of light through the dust-laden air produces those remarkable combinations of bright colors which are so pleasing.

The Warming of the Air. — All space about the earth is intensely cold and the sun's rays pass through it, losing apparently none of their warming power; but as soon as they strike the earth's atmosphere they begin to part with their heat. The air takes a little of the heat, the particles of water vapor and of dust take

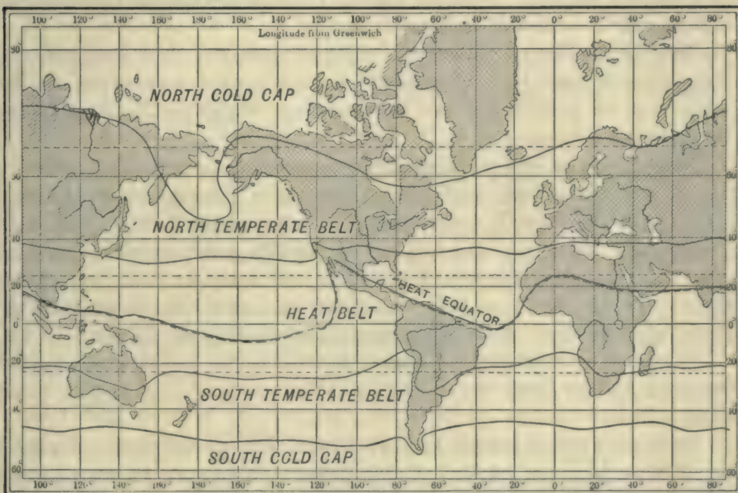

FIG. 365.

Temperature zones.

more, until, by the time the rays strike the earth at noon of a clear day, about one-fourth of their heating power has been lost. The loss increases with the descent of the sun until near its setting, when only a very small proportion of its heat is received upon the earth's surface, owing to the great distance which the rays have to pass through the atmosphere.

Upon what kind of a day does the most heat reach the surface of the earth? Is the heat absorbed by the dust and water particles entirely lost to the earth?

With the aid of a thermometer, determine from what kind of a surface the most heat is reflected. Which absorbs heat rays more readily, the land or the water? Into which does the heat penetrate farther? Why, if there is less heat reflected from the surface of the ocean, does it warm up so slowly?

What can you say as to the depth to which the summer and winter temperature changes are noticeable in the earth? Answer from any observations which you are able to make in openings in the earth, such as wells and tunnels. Describe the condition of the ground in the Arctic regions and the effect of summer heat.

How do the daily and seasonal changes upon the land compare with those upon a large body of water? Find out what you can about the relation of the fruit belt in the North Central States to the Great Lakes. Do these lakes freeze over?

Make observations with the thermometer upon the temperature of the air near the ground and twenty feet above, during the middle of a bright day. If there is a difference in temperature, to what is it due? Explain as fully as you can the reason for the great cold of mountain tops. Explain the difference in temperature between clear and cloudy nights. If the heat from the sun penetrates such a little depth into the earth, what becomes of the large amount received from the sun?

Illustrate by diagrams the reason for the lower temperature toward the poles, and also why the sun's rays in the morning and evening bring so little heat.

An hourly record should be made of the temperature through a number of clear days and nights. Using these data, construct a temperature curve for each day and night. To prepare this curve draw a number of intersecting lines at right angles to one another. Mark the lines running in one direction with the successive hours, while the lines running at right angles to this set will serve to designate the temperatures for the corresponding hours. To complete the diagram, connect the points of intersection of the temperature and hour lines. Prepare a similar table for a cloudy day and night. Note the characteristic differences and explain them.

Mention the main causes, in addition to latitude, which aid in determining the climate of a place. How may we expect the temperature of a summer day preceded by a night of fog to compare with a day when the preceding night has been clear? Give your reasons. What is the effect upon the temperature of a summer day of the presence of much smoke in the air?

What kind of weather results in the greatest variation in tempera-

ture between day and night? In what part of our country are such variations the greatest? Under what conditions will the temperature changes between night and day, winter and summer, be slight along an ocean shore? Illustrate by description of some locality.

What effect have air currents upon the normal temperature of a place? Other things being equal, will a windy place or one where there is little wind be the warmer? Explain how the equalization in temperature takes place when a door is opened between two rooms, one of which is hot and the other cold.

Another fact in regard to the heating and cooling of the air, which we must not overlook, is that compression makes it warmer and expansion colder.

This can be shown by a pump for compressing air, the most convenient apparatus being a bicycle tire and pump. Try the experiment of filling a tire as full as you can. After noting if it has grown warm, let it stand for a time until you are certain it is about the temperature of the surrounding air. Then open the valve, and placing your dry hand in the current of air, note if the air feels cool. If your hand were wet, would the sensation of coolness demonstrate the question under discussion? Give reasons.

A rising current of air, you can readily understand, must be pressed upon by the air about it less and less the farther it extends above the earth. It consequently expands, and in doing so is cooled. A downward moving current is subject to the opposite influence.

Explain, from your own observations, the effect of evaporation upon temperature. What liquids volatilize readily, and how is this fact made use of in the production of artificial cold? Are you more comfortable upon a warm day if at work or if resting? Give reasons for your answer. What principle is illustrated in the use of the fan?

The Moisture in the Air. — Clouds appear, rain falls, and the sky clears, but we must not think that these changes mark the coming and going of the moisture in the atmosphere. We have all seen the water particles collect upon the outside of a pitcher of cold water. We say that the pitcher is "sweating."

Where does the moisture come from and why does it gather on the pitcher? Explain the reason for the moist film upon the window-pane.

This shows that, although it may be invisible to us, there is more or less water vapor in the air.

Place a shallow dish of water outdoors and note what takes place. Where does the water go? Place equal amounts of water in two dishes, and leave one in the wind, the other in quiet air, and note which evaporates first. Will evaporation be more rapid when the air is dry or when it is moist?

If you will observe the surface of a pond of water after the air has suddenly cooled, or in the early morning, a fog-like mist may be seen rising from it. Explain what is taking place. Under what conditions are we aware that there is moisture in the breath?

No portion of the air is entirely free from water particles. In the desert there is so little water in the air that it rarely becomes visible, while in some parts of the earth the sky is obscured by clouds a large portion of the time.

Every body of water is constantly supplying moisture to the air, and in dry climates this evaporation amounts to a layer several feet in thickness each year. Vapor is formed rapidly during the boiling of water.

The amount of moisture actually present in the air at any given time is its *absolute humidity.* By this is meant the amount of water in a given volume of air, expressed in pounds and ounces.

There is a limit to the capacity of the air to take up water, and this is determined by the temperature. Just as you may dissolve a certain amount of salt and no more in water of a given temperature, but may increase the amount by heating the water, so the air will absorb the vapor of water in amounts proportional to its temperature. When the air has all the water it can hold, it is said to be *saturated.* The ratio between the quantity of water actually present and that which the air can contain at the given temperature is known as the *relative humidity.* What is meant by the statement that the relative humidity of the air is eighty per cent?

Table showing the grains of water vapor in a cubic foot of saturated air (or space) at various temperatures: —

20°	1.235	40°	2.849	60°	5.745	80°	10.934
22°	1.355	42°	3.064	62°	6.142	82°	11.626
24°	1.483	44°	3.294	64°	6.563	84°	12.356
26°	1.623	46°	3.539	66°	7.009	86°	13.127
28°	1.773	48°	3.800	68°	7.480	88°	13.937
30°	1.935	50°	4.076	70°	7.980	90°	14.790
32°	2.113	52°	4.372	72°	8.515	92°	15.689
34°	2.279	54°	4.685	74°	9.006	94°	16.634
36°	2.457	56°	5.016	76°	9.655	96°	17.626
38°	2.616	58°	5.370	78°	10.277	98°	18.671
		100°	19.766				

Using any thin dish, with an outer surface such that you can readily detect any moisture which may gather, partly fill it with water and place a piece of ice in the water. Note the temperature of the room, and then place a thermometer in the water, which should be stirred so that all parts will be about the same temperature. Watch the outer surface of the dish, and as soon as moisture begins to appear upon it, record the reading of the thermometer. This is the *dew-point*, and indicates that the air at that temperature is saturated with vapor. If this temperature should be 46 degrees, the table tells us that the absolute amount of moisture in a cubic foot of air is 3.539 grains. If the temperature of the room is 68, each cubic foot of air could contain 7.480 grains of water vapor. The relative humidity is then 3.539 divided by 7.480, or .4718.

The humidity of the air is constantly changing with the variation in the air currents and the transition from the cold of night to the heat of day. As the air begins to cool toward night, its capacity to hold moisture is lessened; and with the coming of evening the *dew-point* is reached, under ordinary conditions. The air is then saturated. With a farther lowering of the temperature of the air, the ground itself becomes so cooled that moisture begins to collect upon it.

Give reasons why the dew forms more readily upon grass than upon other substances. Tell why it is that upon one night there may be a heavy dew, and upon the following night, although the temperature may be as low or even lower, there is no dew at all. Both nights may be clear or

one cloudy. Explain the different influences exerted by these two conditions. Is dew found more commonly upon windy or upon still nights? Has the fact that a wind is blowing, anything to do with the absence of dew?

What does the presence of clouds in the sky mean as to the relative humidity of the air at points where they appear? What change in the

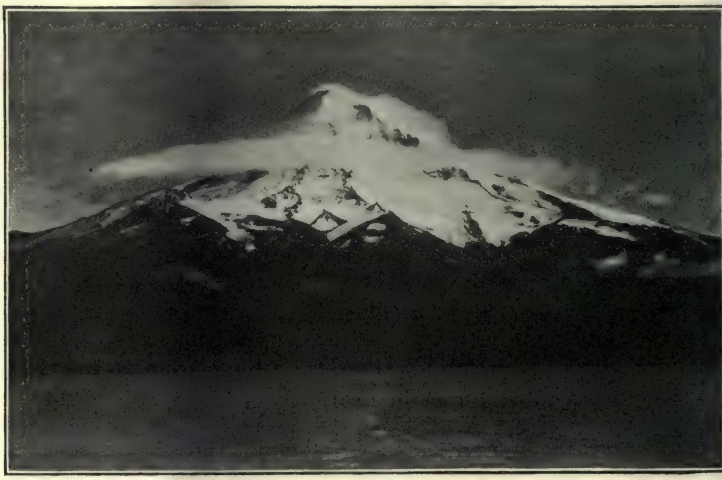

Fig. 366.
Mt. Hood, Oregon.

humidity is indicated when the clouds begin to disappear? Have you ever noted any difference between night and day in the prevalence of clouds or of fog?

Is evaporation always going on over the surface of water? What condition of the air is indicated when a wet garment dries very slowly? If it dries rapidly, what is the condition? Why does drying take place more rapidly when the wind is blowing?

The relative humidity of the air has an important effect upon people. Dry air is invigorating; moist air, if hot, is weakening. Extreme heat can be endured if the air is dry; and dry cold air is not so chilling as moist cold air.

In what portion of the United States is the average humidity the greatest? Compare the hot region about the lower Colorado River with the hot, moist lands along the Gulf of Mexico in regard to healthfulness.

Does all the dew found on grass come from the air? What is the relative humidity when dew begins to form? What are the conditions necessary for the formation of frost? We must remember that frost is

Fig. 367.

Cirrus clouds.

not frozen dew, but results from the freezing of the moisture as fast as it condenses.

What kind of a night favors the appearance of frost? In what situations does it appear last in the spring and first in the fall? What effect has frost upon budding plants and upon the leaves in the fall? In a locality where there is danger to fruit buds from frost, what is the advantage of planting the orchards upon a hillside rather than in the bottom of the valley? Note the temperature of the air as you go from a hill down into a valley in the night or early morning.

The Formation of Clouds. — The study of clouds is an attractive one. We are interested in them, not only for their ever changing form and coloring, but also because they are the source of the rain, on which the life of the land depends.

The clouds come and go seemingly without any reason, but we may be sure that every change in the cloudiness of the sky means

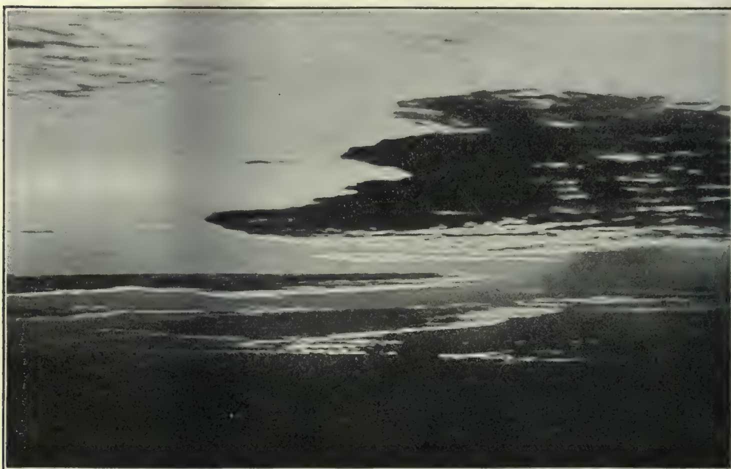

FIG. 368.
Stratus clouds.

a change in the condition of the air. Invisible to our eyes, the currents of air are moving in various directions, and they everywhere contain a greater or less proportion of moisture. If a nearly saturated current comes in contact with cooler air masses, the dew-point is reached and clouds appear. If the temperature is reduced still more, the vapor particles will continue aggregating into larger ones, until drops of rain are formed.

As the air expands it becomes cooler, so that clouds may appear in a rising current without any increase of moisture; while a descending current, becoming more and more compressed, is

warmed, and with the lowering of the relative humidity the clouds disappear.

The long, wreath-like masses of cloud often seen against the side of a high mountain show in an interesting manner the presence of moisture in the air (Fig. 366). Such a cloud is produced

FIG. 369.
Cumulus clouds.

by the temporary cooling of a moist air current as it sweeps by a cold, snowy peak. The cloud particles keep moving, and we think that the cloud ought soon to get past the mountain; but its position as a whole does not change. It is merely the temporary appearance of the moisture near the mountain; and as soon as the latter is left behind, the cloud disappears, since the relative humidity again sinks back to its former condition.

Every portion of the air contains more or less dust. It is derived partly from the surface of the earth, partly from volcanic eruptions, and partly from the meteors which come under the

influence of the earth's attraction. These dust particles, together with the minute ice crystals floating in the upper atmosphere, produce the bright colors of sunset. Their practical value, however, lies in the aid which they give to the condensation of moisture. Each dust particle acts as a center, attracting the still

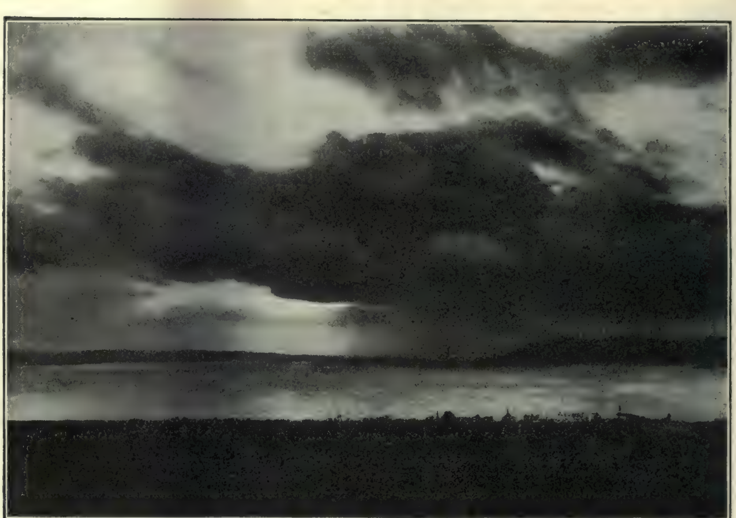

Fig. 370.

Nimbus clouds. A shower over the Golden Gate, as seen from the Berkeley Hills, California.

smaller particles of vapor, until under proper conditions the vapor becomes visible as a cloud. If the temperature is below freezing, the vapor is turned to ice needles; but in whatever state it is, the particles are so exceedingly small that slight currents of air moving upward are sufficient to keep them at great altitudes.

When air filled with clouds is reduced in temperature sufficiently below the dew-point, a further aggregation of the particles takes place, and they soon form drops which fall toward the earth. When the clouds are low, the drops are not so large as they

would be if they had a greater distance to fall, since they usually increase in size during their passage to the earth.

Snow consists of vapor particles which are frozen before they are condensed sufficiently to form drops. The simplest explanation of *hailstones* is that they are frozen raindrops. In many

FIG. 371.

Strato-cumulus clouds. Seen over San Diego Bay, California.

cases, however, their history is much more complicated than that represented by the simple freezing of rain in its fall to the earth.

Often when the air layer next to the earth is very dry, the falling rain from a shower in the upper air may be entirely evaporated before reaching the earth. Describe any such phenomenon which you have noticed. Such showers are particularly characteristic of the arid portions of our country.

In the upper cloud limits, the temperature is generally below the freezing point. The falling of snow upon a mountain, while

in the valley below rain reaches the earth, shows clearly the great difference in temperature in a few thousand feet of elevation.

We distinguish the vapor in the air as *cloud* or *fog*, according as it is at some distance above the earth or resting directly upon the ground.

Fig. 372.

Strato-cumulus clouds.

Fog may be produced by a current of warm, moist air coming in contact with the cool air lying close to a body of water. Fog is also produced during cool nights through excessive evaporation from moist lands. Such fog is particularly characteristic of lowlands and valleys.

Describe all the different conditions which may give rise to fog and mist over a pond or lake. If you have ever been above the fog, describe its appearance. Why does not fog occur in windy weather?

What is the cause of the fog banks off the Newfoundland coast? To what are the summer fogs upon the Pacific coast due? Have you ever seen fog rise and change to cloud? Describe what occurs.

Under what conditions is evaporation from the surface of water most rapid? Discuss the question with reference to the temperature and moisture of the air. Would evaporation continue long if the air were perfectly quiet? Illustrate by some common examples the importance of a current of air for rapid evaporation.

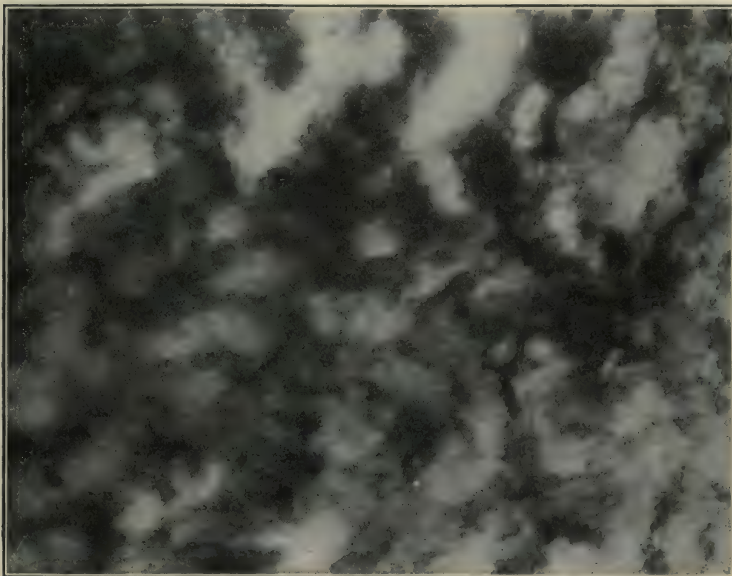

FIG. 373.

Cirro-cumulus clouds.

Classification of Clouds. — Clouds appear under such varied forms that at first it may appear impossible to classify them. Careful observation, however, will enable you to distinguish four main types, and by a combination of these, intermediate forms are produced.

(1) *Cirrus* clouds show bands or delicately mottled layers. Sometimes they assume wisp-like and plume-like forms. Their average height is about five miles (Fig. 367). Floating so high above the earth, where the air is very cold, these clouds are

formed of minute ice particles. Cirrus clouds usually give rise to the halos so frequently seen about the sun and moon.

(2) *Stratus* clouds (Fig. 368) are low, and often blend into fog. They float in the form of bands or layers, hence the name

Fig. 374.
Cirro-stratus clouds.

given them. Stratus clouds characterize periods of stormy weather, although we must not confuse them with rain clouds (Fig. 370).

(3) *Cumulus* clouds pile up in lofty, rounded masses during summer days. Their flat bases indicate the elevation at which the ascending air currents are so cooled as to become saturated. From this base they arise in perpetually changing shapes to a distance of more than a mile. Such clouds are commonly known as "thunder heads" (Fig. 369).

(4) *Nimbus* clouds include the broken, shapeless clouds from which rain or snow is falling (Fig. 370).

Strato-cumulus clouds are the detached masses which spread over the sky in pleasant weather and float with their bases in the same plane (Figs. 371, 372). These clouds often gradually mass together and produce a shower or thunderstorm.

FIG. 375.

Cumulo-nimbus clouds. Summit of Cascade Range, northern Washington.

Cirro-cumulus clouds (Fig. 373) form an aggregate of cottony or fleecy masses, at an average elevation of three miles. They are to be seen in warm, pleasant weather.

Cirro-stratus clouds (Fig. 374) are lower than cirrus and through their formation in horizontal bands are related to stratus clouds. With the approach of a storm they follow the cirrus clouds, frequently giving rise to halos, and are in turn followed by stratus clouds.

In Fig. 375 appear *cumulo-nimbus* clouds piling up against the western side of the Cascade range in Washington. Rain is falling from the nimbus clouds at the base, while above, in the bright

sunlight, cumulus clouds are heaped in lofty, rolling masses. The moist air currents from the Pacific are here being condensed upon the seaward side of the mountains; while above, the drier air of the eastern side dissipates the clouds for some time before they sweep over the mountains and produce rain there also.

From your own observations, distinguish the different classes of clouds. What relation do cirrus clouds have to coming storms? When are they seen? In regard to the cause of the halo, review what was said about light and color (p. 453). Carry on careful observations upon the occurrence of the halo and the kind of weather which follows its appearance.

What clouds are most likely to appear after a storm clears away? What portion of the day is, on the average, the most cloudy? Why is steam most noticeable upon cold mornings? In what kind of weather is the cirro-stratus cloud to be seen?

Have you ever seen clouds piling up over a city or over a large fire? What are such clouds called, and what is the reason for their appearance? Describe the gathering of the clouds upon a summer day, their massing together, and final dissipation toward evening. What time of the day are stratus clouds most frequently seen?

Prepare a written description of the different cloud forms seen as the sky becomes overcast at the approach of a storm, the manner of clearing of the sky after the storm, and the clouds of the following period of pleasant weather.

CHAPTER XX.

THE MOVEMENTS OF THE AIR.

THE WINDS.

Causes of the Winds. — We live at the bottom of an ocean of air, which, unlike the real ocean upon whose bottom there is darkness and perpetual quiet, is brilliantly lighted and in constant motion. The air is not as dense as is the water; light passes through it more readily; while the currents set up in the water as the result of unequal heating are extremely slow in comparison with those of the air.

We feel the pressure of the air as a current strikes us, just as we do the water of a swift stream; but the air is invisible and the currents in it appeal to our eyes only when it is filled with dust or clouds. Air in motion we know as *wind.*

We have already learned that the air, like the water and like the solid earth, has weight and is pulled downward toward the earth; but, unlike solids and liquids, its volume changes very greatly with change of temperature and pressure. The air, then, because of its extreme elasticity flows here and there, now with hurricane velocity, now with gentle currents or breezes, but always toward those points where the pressure is least.

Every current of air that strikes our faces is an illustration of the constant tendency of the air, due to the causes mentioned, to assume a state of equilibrium where all is perfect quiet. The sun, however, is constantly disturbing this attempt at equilibrium, because it heats the air unequally in different places. As a result of these two influences, the air is never at rest over any large area for more than brief intervals.

The difference in air pressure between two places is called the *barometric gradient.* The gradient is steep if the pressure varies

much in a short distance, and gentle if there is little difference in pressure. In the first case the air moves rapidly, just as water does down a steep slope, and in the second it moves slowly; but

FIG. 376.
Effect of the wind upon oak trees. Salinas Valley, California.

we must not think of it as necessarily going up or down. The direction of the air currents is determined primarily by the relative position of areas of low pressure; but it is modified greatly by other causes.

Pick out two weather maps with as strongly contrasted barometric gradients as you can find. What is the reported velocity of the wind where the gradients are steep, compared with the velocity where the gradients are gentle?

Nature of the Air Currents.— Watch the water of a deep stream moving slowly over an uneven bed and you will see that the current is not uniform, but is continually broken by a succession of ever changing eddies. If you continue your observations for a few minutes, you will be able to see the beginning of one of these

eddies. The water in a certain place, as it moves along with the general current, begins to revolve. This motion increases in velocity and a depression is formed at the center, down which the circling water is drawn, to spread out toward the bottom and join in a return movement which again brings it to the surface.

In this manner eddy after eddy arises and disappears in the onward moving current. Some of the eddies are small, others cover a considerable area. Where the eddies are particularly powerful, as in some tidal currents, boats of considerable size, if drawn within the influence of the circling waters, may be sucked down in the funnel-shaped depression at the center.

The currents of air, although not as rigidly fixed or usually as constant as those of the great bodies of water, yet move in defined paths. The prevailing westerly winds in the temperate regions form a good illustration of such currents. Like the current in the stream which you watched, this moving body of air is disturbed within and along its borders by irregular movements which have the form of eddies, and are spoken of in general terms as *cyclones*. Some of these eddies are more than one thousand miles in diameter, and appear and disappear like the eddies in the water. The small, rapidly whirling eddies we know as *tornadoes* and the still smaller ones as *dust whirls*. We shall take these up in detail further along.

Study the air currents for several weeks, and note if there is any one direction from which they commonly move, and if the succession of day and night influences them in any regular manner. Explain some of the important causes for the unequal heating of the air. How do the daily temperature changes in the tropics, temperate, and polar regions compare? What influence upon the range of temperature of a given mass of air has a large body of water underlying it? What influence has a body of land? Which heats more rapidly, pure air or air laden with dust and water particles? Which cools more rapidly at night? Give reasons, based upon your knowledge of gases, why warm air is forced up and cold air is drawn down.

Illustrate with a sketch the course of the air currents established about a lighted lamp or stove.

The General Circulation of the Air.—The last example will aid us in understanding the origin of the general circulation of the atmosphere. The heated air about the fire expands, and thus, being less dense, is pushed upward by the cooler, heavier air that takes its place. The latter, heated in its turn, rises and takes the place of the partly cooled air, which, as it continues to cool, sinks again toward the floor.

The revolution of the earth brings nearly all portions of its surface under the daily influence of the sun.

What determines the width of the belt which during some portion of the year receives vertical rays? Locate upon the earth the belt along which you would naturally expect an ascending current of heated air to exist. What is the origin of the belt of equatorial calms? How does the height of the barometer along this belt compare with its height to the north and south? Does the position of this belt remain unchanged through the year?

We find, then, constant currents of air flowing toward the belt of equatorial calms, or the *heat equator*, as it is called. Here the heated air rises until it attains an elevation where its density is the same as that of the surrounding air. The current now divides and turns toward the poles. As this moving air cools it condenses, and, sinking toward the earth, a part turns back in the direction of the equator, giving rise to the *trade-winds;* while a part continues on toward the polar regions, as the *anti-trade winds.*

The belts of descending air currents are known as the belts of tropical calms.

What can you say as to the relative pressure of the air along these belts? What effect do the changing seasons have upon their position? Compare the position of the heat equator on the January pilot chart of the North Pacific with that on the July chart.

We have spoken of the air currents as though they moved along north and south lines, but such is not the case. The northerly flowing currents are deflected toward the east, because as they move from the tropics toward the pole they are passing from a region

where the velocity of rotation of the earth, as it turns from west to east, is greatest, toward one where it is least. The southerly moving curents are deflected toward the west, because they are moving from a region of less velocity of rotation to one of greater.

Compare the velocity of a particle of mud attached to the rim of a wheel with one attached to the middle of a spoke and another upon the hub. Illustrate the fact that an object in motion tends to continue in the same direction. Why is a person standing in a rapidly moving car thrown against the outer side as it rounds a curve?

The deflection of air currents due to the rotation of the earth can be illustrated by means of a black globe and a piece of chalk. Revolve the globe in a direction opposite to that of the hands of a clock, and, beginning at the north pole, draw the chalk over the moving surface in a direct line toward the equator. If the globe were quiet this line would coincide with a meridian, but under the circumstances it curves toward the right at an ever increasing angle as the equator is approached.

The general air currents in the northern hemisphere are a counterpart of those in the southern; but in the latter they are more regular, owing to the lesser amount of land.

As the air sinks in the belts of tropical calms, it divides, as has already been stated. In the northern hemisphere the southerly or return current turns toward the west and becomes the *northeast trade wind;* while the other portion of the current, the anti-trade wind, is deflected more and more toward the east, and is known finally as the *prevailing westerly.* This current is particularly characteristic of the temperate latitude, but is more regular and unbroken at great elevations than near the surface of the earth. Records made at the summit of Pike's Peak show that fully seventy per cent of the winds in that region blow from some westerly point.

Still farther north, this easterly deflected current is known as the *circumpolar whirl;* for while a portion of it returns near the surface, forming light northeast winds, the greater part appears to rise with a spiral movement, for the areas about the poles, particularly the southern one, are characterized by low pressure.

Prepare a sketch of the successive wind zones and calms encountered as one goes either north or south from the equator. Mark the zones of high and low pressure. Find out what you can about the storms and winds encountered in the equatorial regions. In what parts of the world are the currents of the general circulation the most regular and uniform? What influence upon them have large bodies of land? How do these regular winds and belts of calms affect the routes of sailing ships?

Give the results of your observations as to the direction from which the winds commonly blow in the region of your home. During what season of the year are they most regular?

Explain the reason for the fact that upon the eastern side of the continent the general westerly current is affected during the summer by the presence of the Atlantic. In answering this question, find out which is warmer in summer, the land or the water, and what the tendency of the local air currents would be under the conditions observed to exist. Upon the Pacific border the westerly winds blow with far more force and regularity during the summer than during the winter, for the latter is the period of storms. What effect upon the force of the westerly winds has the summer temperature of the land upon the Pacific border?

Nearly all portions of the land, especially mountainous districts and coastal regions, are characterized during fair weather by more or less regular wind changes every twenty-four hours.

Describe, from observations which you have recorded, the daily variation in wind currents. Note the time of the day when there is the least movement of the air. State any observations which you have made upon the night and day breezes of a mountain slope.

As the sun's rays strike the earth in the morning, the layer of air nearest the ground is warmed first, as you can readily show by experimenting with a thermometer in different positions. This warm air upon a sloping surface, such as a mountain side, expands, and thus becoming lighter, is forced out of the way by the colder, heavier air above. It begins to move upward along the surface, as this is the direction of least resistance, thus giving rise to the daily valley breeze. At what season of the year is this current of air most noticeable?

The cool night breezes down a mountain side originate as a result of a process the reverse of that just described. Explain

why as night comes on the air cools more rapidly toward the summit of a mountain than it does in the valley below. As the cool air sinks, it is guided in its movements by the ridges and depressions of the surface, and in this manner well-defined currents are formed in the canyons. Where the slopes are favorable and a number of canyons unite, it frequently happens that a very strong wind is produced.

At what time of the night do these currents of air reach their maximum? Are they stronger upon a clear or cloudy night?

State, from your own observations, the relative rate of absorption and radiation of heat of land and water. Find out what you can about the daily variation of the air over the ocean compared with that over the land.

The air over the land, rapidly warming under the influence of the morning sun, expands and is slowly displaced by the air lying over the adjoining portion of the ocean, which does not warm as rapidly, owing to the lesser reflection from the surface of the water.

Illustrate with sketches the course of the air currents in the land and sea breezes. At what periods in the twenty-four hours during fair weather is the air in equilibrium? Explain fully the cause for the breeze from the land at night.

As a usual thing the daily sea breeze is gentle; yet when the surface of the land is so shaped as to give a free sweep up a converging valley, it is increased, like the tides in a long, narrowing bay. The Salinas Valley (Fig. 376), opening back from the coast of California, lies in such a direction that the daily sea breeze sweeps into it unobstructed. The valley slowly converges and is bordered by high mountains for a distance of seventy-five miles. The daily breeze does not reach the upper end of the valley until late in the afternoon, but by that time it has increased to almost the strength of a gale, and continues to blow until after midnight.

Note carefully if the geographic features in your vicinity have any particular effect upon the winds. Almost every locality has some peculiar

winds. Observe and describe any such winds in your home region. If you live near the ocean, note the relative importance of the daily wind changes in winter compared with those in summer. Find out about the wind currents in caves, and their relation to day and night.

Local Winds of Irregular Occurrence. — There are many local winds more or less related to the great cyclonic disturbances, and it is of these winds that we now want to learn something.

A warm, dry wind of the Alps is known as the *foehn* wind and originates in the following manner. An air current crossing a mountain range, even though it be laden with moisture when it first encounters the mountains, may be robbed of so much of this moisture in the cool regions of the summit that, as it descends upon the opposite side, it becomes a dry wind. By the time it has reached the lowlands it has been so warmed by compression and its relative humidity so lowered that, if it blows in winter, the snows are quickly melted, and if in spring, the ground is dried and vegetation injured.

Review what has been said about the effect of expansion and contraction upon the temperature of gases (p. 457).

A wind similar to the foehn wind of the Alps, but occurring upon the eastern slope of the Rocky Mountains, is known as the *chinook* wind, from the fact that it blows apparently from the direction of the mouth of the Columbia River, where dwelt the Chinook Indians. This wind, after crossing the lofty ranges of the Rockies, descends to the valleys and plains, melting the snows and bringing spring-like weather.

Find out from reference books all that you can about the *sirocco* and *simoon* winds. Describe the causes and characteristics of the "northers" of the Texas region and the "blizzards" of the Great Plains.

Upon the Pacific slope there is a *desert wind*, which sometimes does a great amount of damage to the vegetation of the cultivated districts. These desert winds have much the same character as the chinook wind, their warmth and dryness being partly due to

the same cause, and partly to their passage over the deserts. They blow from northerly and easterly points. In Southern California the desert wind is known as the *santa ana*.

Cyclonic Winds and Storms. — The common dust whirl, which every one has seen, is the best illustration upon a small scale of the movement of the air in a cyclonic disturbance. Tornadoes and waterspouts picture to the eye an intensified form of the air whirls, but these are limited to certain regions.

Cyclonic storms resemble closely the eddies appearing and disappearing in a stream of water (p. 473), and occur as disturbances in the regular air currents. In low latitudes they move westerly, and in high latitudes they have a general easterly direction. These cyclonic disturbances vary in size from the little dust whirls of a few feet in diameter, to the great storms which sometimes exhibit a diameter of more than one thousand miles.

According to the direction of the movement in these revolving air whirls, we distinguish two kinds, *cyclonic* and *anticyclonic*. In the first the movement of the air is from right to left and upward; while in the second it is the reverse, that is, from left to right, like the hands of a clock.

The tendency of movements in a liquid or gas to assume a spiral course can be observed, not only in the current of a stream as already noted, but also in the currents formed about a small opening in the bottom of a washbowl or bathtub. Put a little coloring matter into a vessel with such an opening, and describe carefully the nature of the movements which are set up as the water flows out.

The whirls in the atmosphere, in addition to having a motion of their own, are carried along by the onward sweep of the air currents in which they occur. Their direction is often irregular, and the rate of progression variable, lying between fifteen and seventy miles an hour, the average being perhaps less than thirty miles. The velocity of the wind does not depend upon the rate of progression of the storm, but rather upon the rapidity of the

motion of the whirl. The cyclonic storms which move rapidly have usually much less extent than those of slow movement; they are also more severe than those which spread out over a large territory. This fact is illustrated in the case of tornadoes, whose narrow paths are marked by such destructive winds.

As the cyclonic and anticyclonic whirls sweep over the surface of the earth, there are definite changes in the direction of the wind and in the barometric pressure.

By means of a circular diagram illustrate a cyclonic area moving from west to east. Describe the succession of winds which an observer would experience if he were in the path of the center of the storm. Draw another diagram illustrating the direction of the wind in an anticyclonic area, and the changes experienced by an observer similarly situated.

With the coming of a cyclonic disturbance the pressure of the air decreases as it commences to be drawn spirally upward in the great whirl, and the mercury in the barometer begins to fall. The rate of fall of the mercury tells us whether the storm is moving rapidly or not, and the commencement of a rise indicates that the center of the whirl has passed.

In what kind of a storm is the barometric gradient steep? When is the wind velocity likely to be very great?

The velocity of the wind is greatest between the edge of the storm and the center. At the latter point there may be no wind at all, because here the movement is wholly upward instead of horizontal or oblique.

As the anticyclonic area follows the cyclonic, the barometer rises to a point above the normal, owing to the downward movement of the air. The frequency and intensity of these changes vary with the seasons. They are more numerous and better defined in the winter than in the summer.

With the aid of a series of weather maps showing well-marked cyclones, or "lows," and anticyclones, or "highs," note the variation in barometric pressure between their centers and outer margins. Note the steepness of the barometric gradient, and compare it with the extent of

the disturbance. Choose several maps showing the progress of a storm from the time of its first appearance upon the northwest coast until it disappears off the Atlantic border. Determine the rate of progression. Note, further, whether the areas of high pressure (anticyclones) are as well defined as the areas of low pressure. What is the greatest range in the barometric pressure shown? Pick out a map showing but slight variations in barometric pressure and read what is said with reference to the wind velocities. Note the wind velocities connected with the high and low pressure areas.

The eddies of the atmosphere appear to be of two classes. The first include the cyclonic and anticyclonic areas already described, which originate in and move easterly with the general air currents of the temperate zones. The causes leading to their formation are not clearly understood. The second class includes those disturbances which are due to *convection*, that is, to the mixing of air currents of unequal density. Here are to be placed dust whirls, the cyclones and tornadoes of the United States, and possibly tropical hurricanes; although our lack of knowledge of the circumstances leading to the formation of the latter make their proper classification doubtful. The revolving storms just mentioned, while of the same general nature as the cyclonic disturbances of the first class, are of less extent, but exhibit a much greater intensity.

A dust whirl is the simplest and most easily studied example of those dangerous storms formed through convection. They occur in all parts of the country, but are particularly characteristic of arid regions. Upon a warm morning a dozen dust whirls may be seen at the same time moving over the surface of a western desert. Their appearance indicates that the generally quiet air is getting into an unstable condition, and that before long the regular daily wind will arise.

The starting of a dust whirl may be explained as follows: The bare earth reflects into the air much of the heat received from the direct rays of the sun, and before noon this lower layer of air becomes greatly heated, while that some distance above

still remains comparatively cool. The air now is in unstable equilibrium; that is, dense, cool air overlies warmer rarefied air, and a slight disturbance will upset these layers so that the heavier will sink and displace the lighter, thus starting a current. As the light air moves upward, an indraft from the sides

FIG. 377.

Galveston Hurricane.

(From Professor Willis L. Moore's forthcoming book on Modern Meteorology.)

takes place, and this quickly assumes a rotary movement, just as the water does while running out of the opening in the bottom of a washbowl. The vortex begins to move over the ground, picks up the fine, loose earth and other light materials lying in its path, and, with a rushing sound, whirls them high in the air. With the general upsetting of the lower heated layer of air the daily wind begins and blows through the afternoon, sweeping over the desert, often with great force.

Find out what you can about the *typhoons* of the Pacific Ocean and the *hurricanes* of the Atlantic. Much valuable information along this line can be obtained from the pilot charts of the United States Hydrographic Office.

How do the extent and severity of the Atlantic hurricanes over the region of the West Indies compare with their extent and severity by the time they have reached the eastern and northeastern shores of the United States? Seek for sea narratives giving descriptions of hurricanes and typhoons. Learn what you can about the Galveston hurricane (Fig. 377).

Upon the borders of what belt of winds do these cyclonic storms originate? At what time of the year are they likely to occur? Give the succession of winds at Charleston during the passage of a hurricane.

The hurricanes and typhoons, in recurving toward the east after reaching the temperate latitude, take on the characteristics of the normal cyclonic disturbances of the westerly air currents. A typhoon of the China Sea has been traced across the Pacific Ocean and North America, making a circuit of nearly half the globe before its energy was entirely spent.

The *tornado* is a violent and local cyclone or air whirl, which is marked by the presence of a dark, funnel-shaped cloud. This cloud revolves rapidly with an upward sucking movement at the center, and travels over the surface at a high speed. We might consider a tornado a dust whirl upon a gigantic scale. Tornadoes rarely travel a distance greater than from one hundred to two hundred miles, and usually have a diameter of less than one thousand feet.

Tornadoes develop in the warm, moist air upon the borders of low-pressure areas, and have a direction from southwest to northeast.

If you have never seen a tornado, obtain from some description an idea of the characteristics of such a storm and the destruction which it frequently accomplishes. What portion of our country is most frequently visited by tornadoes? At what time of the year are tornadoes most frequent? What are the conditions of air and temperature which tend to produce a tornado? How do the conditions differ from those giving rise to a dust whirl?

Temperature and Rain of Cyclonic Storms. — Low-pressure areas are normally centers of cloudy and stormy weather, while high-pressure areas are clear.

Using a number of the weather charts of the United States for different days, compare them with reference to the distribution of the areas of high and low pressure and the rainfall areas. Search for a map upon which there are no well-defined areas of low pressure and note what is said with regard to the weather conditions and the extent of the rain areas.

From a study of a number of the weather maps, determine whether the rainfall area is in each case distributed symmetrically about the center of the accompanying low-pressure area, or lies mostly to the east of it. From your own observation, state whether the rains are as heavy and long continued after the center of the storm has passed as during its approach. State the reasons for any facts of this kind which you may discover.

Compare the temperature of any point in the upper Mississippi Valley during the passage of a storm area, with the temperature of the succeeding "high." What is the general character of the weather during the existence of the latter condition?

There is a spiral upward movement of warm air about the center of a storm, and this air, as a result of its cooling and condensation and consequent increase in humidity, offers the first condition necessary for the formation of rain. It will be readily understood, however, that, if the air is very moist to begin with, the precipitation will be much heavier than if it is dry. In fact, a storm may come in upon the land from the Pacific accompanied by heavy rains, but be so robbed of its moisture that over the plateau region rain may nearly cease falling, although the depression of the barometer be just as great. If you will follow such a storm across the United States, and down the St. Lawrence Valley, you will find that as soon as it comes within reach of the moist air currents from the Atlantic, the rainfall will increase.

Can you tell why there is frequently a clearing of the clouds at the center of the storm? What effect have mountain ranges upon the precipitation of a passing storm?

We may consider rain due to the cooling of a moist, ascending current to a temperature below the dew-point. The cooling of the air is brought about mainly through its expansion; but in mountainous regions the cold, lofty elevations aid in the reduction of temperature, with consequent increase in precipitation.

Draw diagrams illustrating the movement of the air in both cyclonic and anticyclonic areas. Why are the latter characteristically pleasant? Why is the air of the anticyclone cool, and that of the cyclone warm? In what way does the presence of clouds and moisture in the air aid in producing this difference? What is the relative rate of radiation in clear air compared with foggy or misty air?

Become familiar with the appearance of the sky at the approach of a storm. What are the first clouds seen? From what point does the wind, where you live, first begin to blow at the approach of a storm? From your own observations, state whether a storm of large or of small dimensions gives rise to the strongest wind.

Have you ever known it to rain without a fall in the barometer? When an area of high pressure becomes practically stationary in the plateau region of the West, what effect does it have upon the weather of the Mississippi Valley?

A "stagnant" area of high pressure in Nevada will force the storm centers to travel across the country farther north, and give a dry winter in California. A high pressure in the interior near the Canadian boundary will force the storms southward, and the arid portion of the country will receive an unusual wetting.

Careful observations should be carried on and records kept for some time during the winter months, until the succession of phenomena connected with the cyclonic and anticyclonic whirls is completely understood. The winds following the passage of a storm are much cooler than those that precede it. Mention the different causes which might account for this fact.

Under what conditions do the moist winds blowing in from the Pacific bring rain? Such winds characterize the Pacific coast in summer, but there is usually little or no rain through July and August. Explain the reasons for this fact.

From a study of the weather maps, determine the position of the cold wave so frequent in the winter, in its relation to "highs" and "lows."

From which direction come the moist winds of the central and eastern United States? Are the winds of the anticyclonic areas as strong as those of the cyclonic areas? Base your answer partly upon your own observations of the weather, and partly upon a study of the weather map.

When water boils away rapidly, the cook says that it is going to rain. Is she right, and what does the phenomenon imply?

Thunder-storms. — During warm, summer days, when the air is unusually moist, the ascending currents from the heated ground reach an elevation at which they are so cooled that the dew-point is reached and cloud patches begin to form. These gradually enlarge, and in the afternoon pile up in lofty, curling masses, which have a dark, threatening appearance below. Rain finally begins to fall and the accumulated electricity is discharged between the clouds or from the clouds to the ground. The falling rain cools the adjacent air and starts a downward current, which produces a strong gust of wind at the front of the storm, as it slowly moves along.

Describe the general character of a day upon which thunder-storms may be looked for. Make careful observations of a number of thunder-storms, describing the gathering of the clouds, the wind currents, the rain, and the manner of clearing. Explain the occasional occurrence of hail and note the temperature of the air before and after the storm.

Thunder-storms are frequent in mountainous regions, and are due to the currents of warm air ascending the slopes toward the cool regions about their summits. The influence of mountain peaks in producing condensation is strikingly shown in arid regions, where the sudden cooling in the upper atmosphere of the strong currents from the hot lowlands may produce a short but heavy rainfall. The "cloudburst" is nothing more than such a rain upon a barren, unprotected surface from which the water can quickly collect in the arroyos and gulches.

Why are not thunder-storms likely to occur during windy weather? If your home is in or near a mountainous country, describe the effect which you have observed elevation to have upon storms. Are thunder-storms more likely to occur over low or high land? Why?

CHAPTER XXI.

THE CLIMATE OF THE UNITED STATES.

Introduction. — The relative amount of moisture, the presence or absence of clouds and storms, the intensity and character of the winds, the calms, the temperature and pressure of the air, are all taken into account when we speak of the *weather* which is experienced in a given place. The average or combined result of all the things mentioned above determines the *climate* of a place or country.

Give in detail the present weather conditions of your home region. Give the conditions at the time of the year when the weather is usually the most disagreeable. What conditions rule in the pleasantest season of the year? How long a period would you take into account, in arriving at a conclusion as to the climate of a place? From what you have learned as to periods of drought and of years of light and of heavy rainfall in your home district, how long a time would you want to be acquainted with a new country before being sure that you knew all about its climate?

Into what zones is the climate of the earth divided? In which of these does the United States lie? Trace out upon a chart showing the isotherms the boundaries of that zone in the northern hemisphere whose average temperature lies between the isotherms of thirty and seventy degrees. Explain the northward curving of the isotherms over the Atlantic and Pacific oceans and their southward curving over the North American continent. Give all the causes which lead to this great variation of the isotherms from the parallels of latitude.

There are three main types of climate in the United States: that of the Pacific coast, that of the interior, and that of the Atlantic region.

How does the climate of the interior of the continent differ in a general way from that of its borders? What is the reason that the Pacific

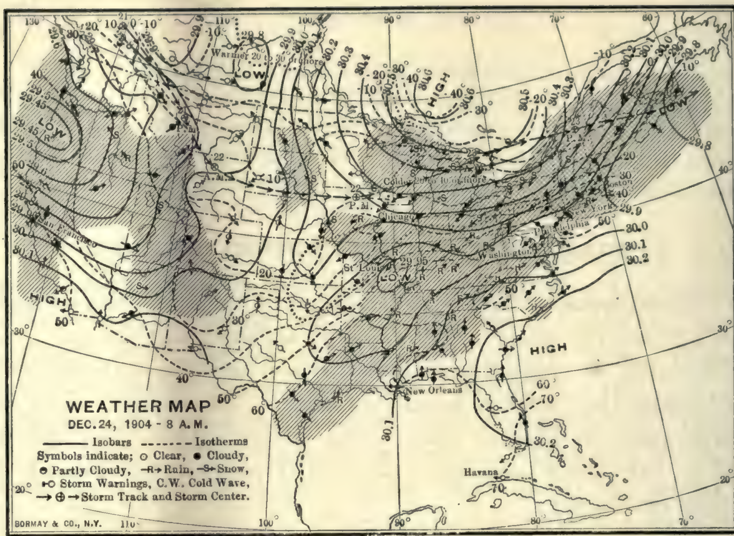

FIG. 378.

A winter storm coming in upon the Pacific coast from the ocean.

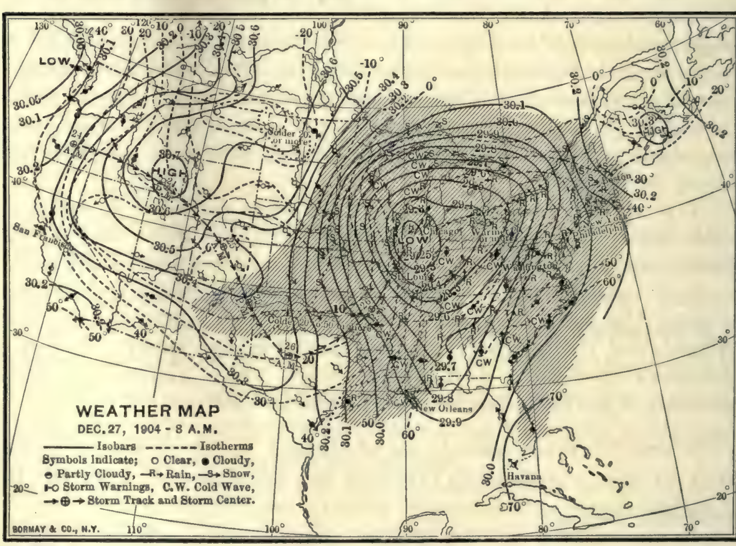

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FIG. 379.

Storm that during two days following December 24 (Fig. 378), passed far south and then recurred northeast. Note extent of rain area and its relation to the storm centre.

coast climate differs so greatly from that of the eastern part of the continent? In what way does the position of high mountains along the western border of the continent affect the climate of the interior? If the position of the eastern and western highlands was reversed, what changes would be brought about in the climate of the country?

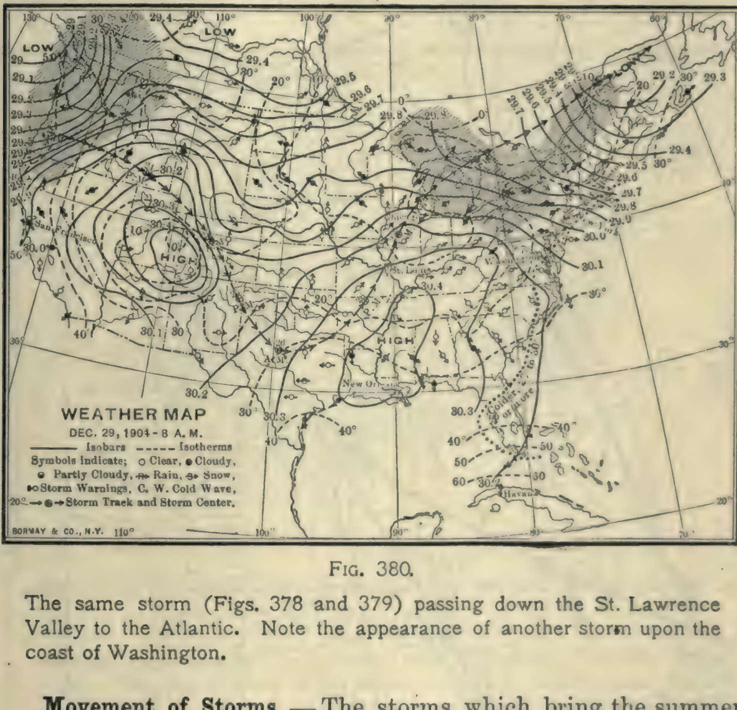

FIG. 380.

The same storm (Figs. 378 and 379) passing down the St. Lawrence Valley to the Atlantic. Note the appearance of another storm upon the coast of Washington.

Movement of Storms. — The storms which bring the summer rains to northern Mexico and the southern portion of the plateau region, do not come in from the Pacific, as do the winter storms, but, originating in the intensely hot region of the gulf, move in a northeasterly direction, so that they rarely affect any portion of Southern California.

Study a sufficient number of the weather maps to determine the starting points and different paths pursued by the storms in crossing the country (Figs. 378–380). Toward what point do most of them

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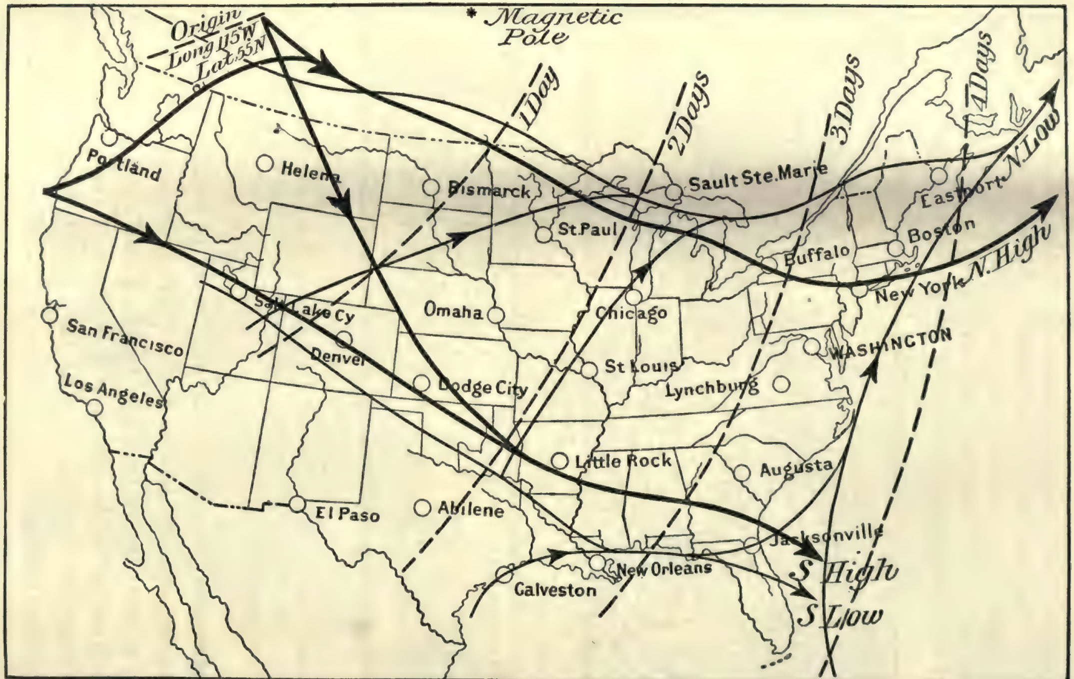

FIG. 381.

Mean track and average daily movement of storms in the United States.

(From the United States Weather Bureau.)

converge? Define in a general way the path which the greater number pursue. Observe upon the summer weather maps the almost constant "low" hanging over the region about the head of the Gulf of California (Fig. 382).

Indicate the course of the tropical hurricanes which visit the United States. At what season of the year may they be expected?

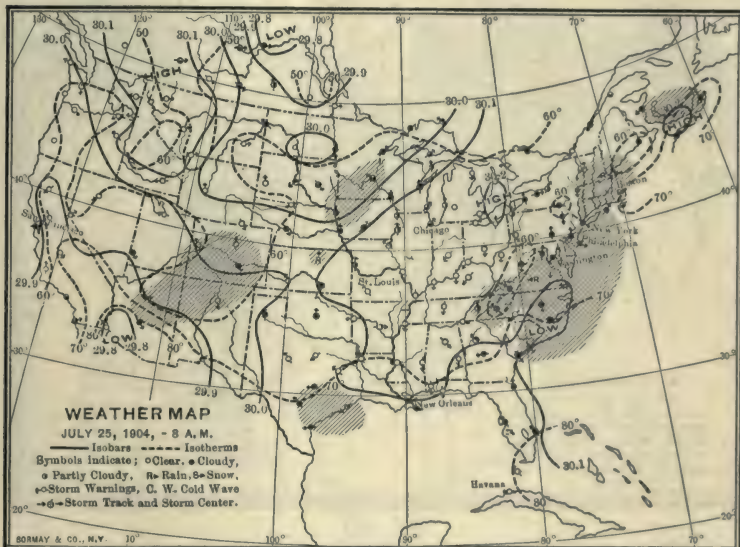

FIG. 382.

Weather map showing characteristic summer conditions in the United States. Note the absence of any very pronounced "highs" and "lows." Note also the area of low pressure marking the region about the mouth of the Colorado, and giving rise to the summer showers of the southwest.

Do you find that any relation exists between the size of the hurricane and its energy? Follow the reports of some storm (Figs. 378–380), and note if its character changes as it progresses.

Compare the paths of the cyclonic areas across the United States in July with those of January. What general difference appears? What can you say as to the variability of the weather in a zone of frequent cyclones and anticyclones? What part of the United States is marked

by the fewest storms? What are its general climatic characteristics? Using the Weather Bureau Charts, plot upon a map of the United States the paths of the storms for January and July.

What effect has the presence of the Sierra Nevada-Cascade Range upon the evenly tempered winds from the Pacific Ocean? Why is

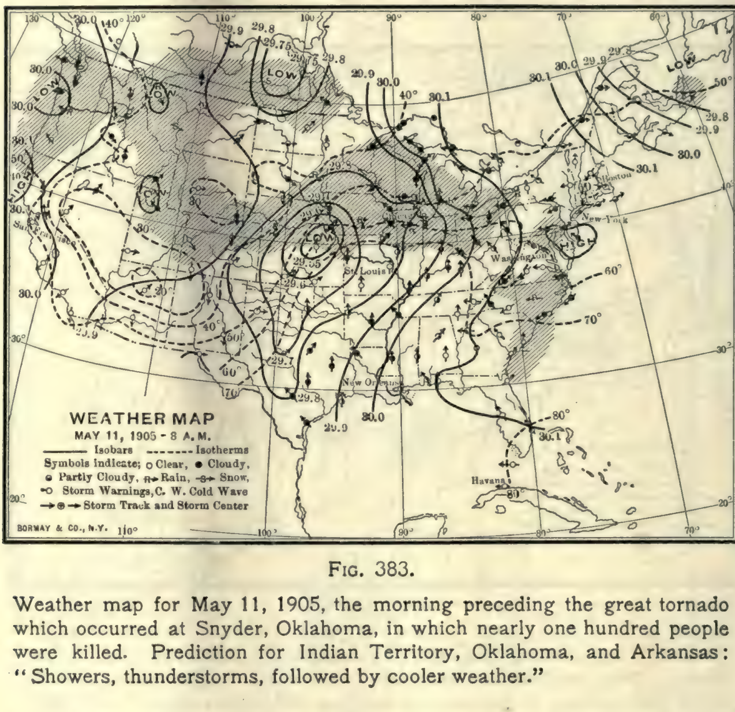

FIG. 383.

Weather map for May 11, 1905, the morning preceding the great tornado which occurred at Snyder, Oklahoma, in which nearly one hundred people were killed. Prediction for Indian Territory, Oklahoma, and Arkansas: "Showers, thunderstorms, followed by cooler weather."

the rainfall of Southern California so light? Find out what you can about the climate of the Death Valley region, and explain the reasons for its peculiarities. What is the lowest annual rainfall recorded in this part of the United States? Review what has already been said about the influence of mountains in relieving this region from utter barrenness (p. 288). Give a general description of the climatic conditions of the Pacific Coast. Oranges ripen in the Great Valley of Northern California six weeks earlier than in Southern California. What is the reason?

Give a detailed description of the climate in the Great Basin and Plateau region, using any available source of information. Why are the daily and seasonal temperature changes so much greater here than near the Pacific? What is the general relative humidity of the desert portions of the interior?

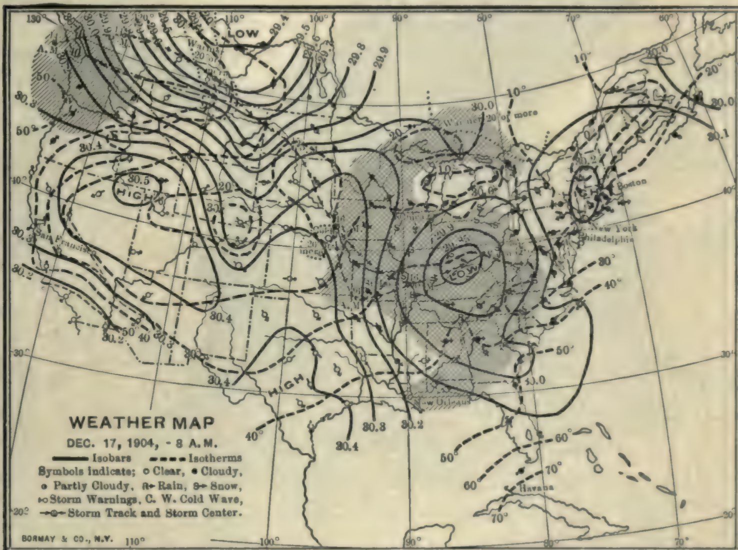

FIG. 384.

A "stagnant high," covering the western United States. This causes the storms coming in from the Pacific to keep a course far north until the Mississippi Valley is reached. The long continuation of such conditions during winter gives rise to a dry year in California.

During the prevalence of a desert wind at San Diego in December, 1903, when the temperature was 73, the dew-point was −11 (that is, 11 degrees below zero) and the relative humidity 3. This is one of the driest conditions of the air on record. Review what has been said about the dew-point and relative and absolute humidity (p. 458).

Temperature. — The temperature upon the borders of Puget Sound, which is in the same latitude as North Dakota, never descends more than a few degrees below the freezing point; while in the latter region we find the lowest temperature recorded in

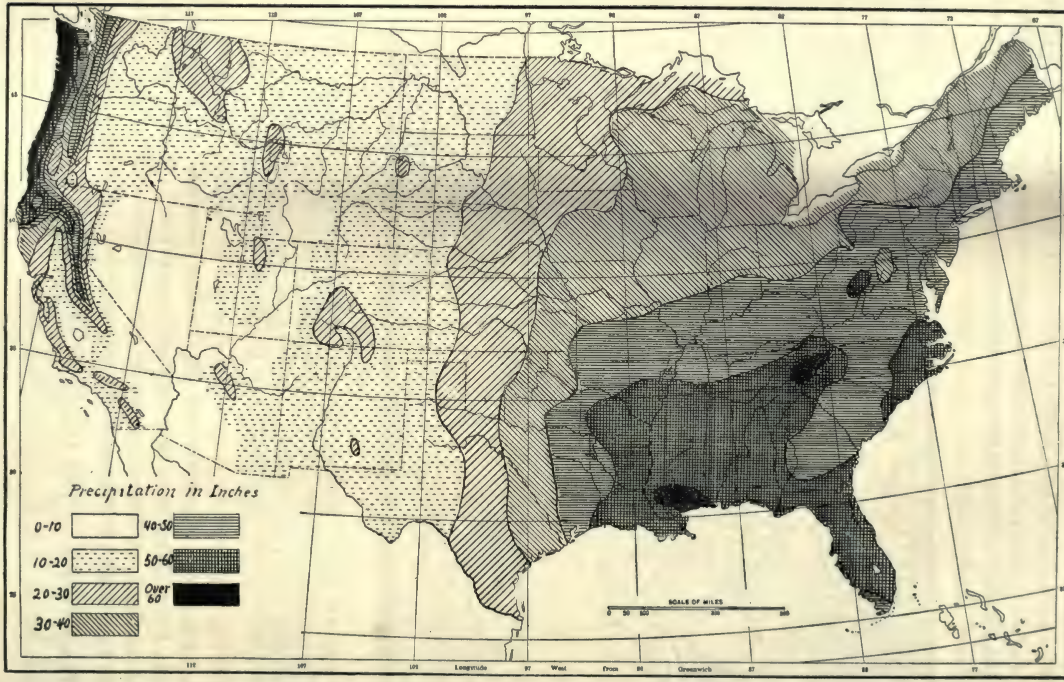

Fig. 385.

Rainfall map of the United States.

p. 494

the United States outside of Alaska, namely, sixty-four degrees below zero.

Give the factors which have brought about such a state of affairs. Find out what you can about the climate of the eastern slope of the Rocky Mountains and Great Plains.

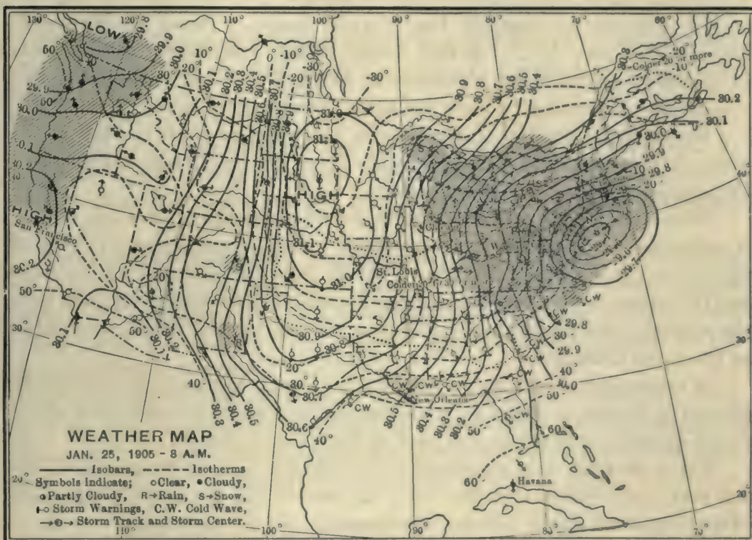

FIG. 386.

A high pressure area, accompanied by extremely cold weather in the northern United States and freezing temperature as far south as Florida.

Rainfall. — Trace out, upon the rainfall map (Fig. 385), the line extending nearly north and south across the Great Plains marking the limit of twenty inches or more of rainfall. East of this, farming can be successfully carried on without irrigation, while to the west irrigation is generally necessary.

In the dry regions of the Great Basin, evaporation is enormous. Great Salt Lake loses from its surface a thickness of water of about eighty inches every year; while from Lake Michigan the evaporation is but twenty-two inches.

The rainfall of the South Atlantic and Gulf States is heavy, while that of western Mexico and southern California is light.

Why is there such a difference in these two regions, since both lie outside the track of most of the cyclonic storms which pass easterly across the United States? How does the direction of the prevailing winds of winter differ from those of summer in the region along the Gulf? For answer consult the weather maps. What weather conditions give rise to the severe frosts which sometimes visit Florida (Fig. 386)? With what atmospheric changes are the "blizzards" and "northers" associated? How far south does their influence extend?

During what portion of the year is there the greatest rainfall in the upper Mississippi and Ohio valleys? How do the Great Lakes affect the climate of the lands about them?

Why are not the same contrasts found upon opposite sides of the Appalachian Mountains as those which prevail upon opposite sides of the Sierra Nevada-Cascade range? Why does the Atlantic Ocean temper the winter cold of the eastern continental border so slightly that here the thermometer sinks almost as low as in the interior of the continent at the same latitude?

What conditions of the air lead to the heated spells of summer in the central and eastern States? What are the atmospheric conditions which result in warm winters in this part of the United States?

Carry on your own observations in connection with the study of the weather maps for a sufficient time to enable you to make predictions of the weather a day or two in advance.

Much of this work it will be necessary for you to carry on with the aid of the barometer, thermometer, rain gauge, etc.; but while doing the mechanical part, do not neglect to train your eyes in the observation of the signs of the sky. The ability to interpret the meaning of the winds and the clouds, without the aid of instruments, determines in large measure the practical value which you will get out of the work.

CHAPTER XXII.

FORESTS AND FORESTRY.

Introduction. — Wherever there is sufficient moisture and the cold is not too severe, the earth's surface is covered with a growth of vegetation.

Describe the manner in which plants obtain their nourishment. Is the quality of the soil as important a factor as temperature and moisture? Review what has been said (p. 116) with reference to the formation of the soil.

From your reading, give a general description of the vegetation of the moist tropics. In what countries is the tropical vegetation most dense and impenetrable? Tell what you can about the plants of the semi-tropical deserts. In what way are they peculiarly adapted to living upon a small amount of water?

What is the general character of the vegetation of the tundras? Why are trees absent from the tundras? Of what portion of the earth are palms native? Tell what you can about the distribution of coniferous trees. What trees predominate in the vicinity of your home?

When man first appeared upon the earth, his home was probably in a densely forested tropic or semi-tropic region. He found among the trees shelter from the storms, as well as protection from the other animals. Primitive man had few if any implements, and so made no inroads upon the forests.

As men rose out of their primitive condition and increased in numbers, they began to find use for the trees in building homes. The bark was especially sought after for this purpose, and it came to be used much in the making of baskets and for other domestic purposes. Canoes were hollowed out of the large, straight trunks or made from the bark, as in the case of the birch tree.

During the time of the early civilizations of southern Europe and western Asia, the forests in these regions began to be used

to a large extent, and their destruction has continued at an increasing rate over a wider and wider area. As a result of this careless use, and aided by fires set during wars and those resulting from accident, large areas of once fertile country are now barren and but sparsely populated.

The people of central Europe, particularly the Germans and Swiss, have for nearly one thousand years guarded their forests with great care, cutting them down no faster than their growth is renewed. For a long time all the industries connected with and dependent upon the forests have been carefully regulated.

Forestry, in the narrow sense, is the art of cultivating the forest for the purpose of maintaining a constant supply of its products. This was in earlier years the sole object which forestry sought to accomplish. Lately, however, the great value of the forest as a preserver of the water supply and as a covering to protect the soil from being washed away, has come to be better understood, and this has enlarged our conceptions of forestry.

Besides these two views of forestry, there is still another, which did not appeal so much to our ancestors as it does to us. This third side has to do with the preservation of portions of the forest areas, particularly in wild and picturesque regions, as pleasure and recreation grounds. Our ancestors lived among the forests, thinking little of their wonders and beauties; but now, as a result partly of a growing love of nature and partly of our unnatural indoor life, which shuts us away from contact with nature much of the time, we are coming to appreciate the physical world more thoroughly. For these reasons we demand that portions of our country, where the climate is invigorating and where the forests and rocks lend attractions, be left unmarred by industrial operations. Living out of doors a portion of each year, we shall grow physically stronger and have cultivated within us those simple tastes and ideas which contact with nature fosters.

The Forests of the United States. — The forests of our country form one of its most important resources. Mineral deposits when

once exhausted are not renewed; but the forests, if properly cared for and carefully used, will continue to renew themselves.

The portion of the continent first settled was found to be densely forested. Great labor was required to remove the trees before the land could be used in raising the necessary food supplies. For this reason the forests were long regarded as a nuisance, rather than a blessing. The thought that the forests might sometime give out never occurred to the pioneer settlers.

But as time went on, and the country grew in population and new industries developed, the demand for all sorts of products derived from trees increased rapidly, until at the present time the primitive forests are being destroyed at a rate which will cause them to disappear in nearly all parts of the country within the next fifty years.

The lumbermen are extending their operations into more and more remote districts, and in most cases are stripping the country with no thought of the effect upon the water resources and timber supply of the future.

A greater wealth of forest has fallen to us than to almost any other nation, but until recently this has not been appreciated. We have not had in mind the fact that forest growth is slow, and that the noble trees which we are now cutting down have been hundreds of years in attaining their present size. We have had no care for the needs of the people who shall come after us. The forest areas have been stripped, as though it was our intention to abandon the country when we had gotten all that we could out of it.

It is important, then, at the present time, that we should learn something about the conditions which have produced our forests, and the best manner to retain them, while at the same time taking from them the materials needed for our industries.

Describe the uses of the various parts of the tree, such as the body, the limbs, the bark, and the juices. What trees produce turpentine and resin? What ones are valuable for tanning purposes? for making paper?

p. 500


FOREST REGIONS
OF THE
UNITED STATES
The Unshaded Areas are Treeless, Except
Along the Streams.
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
INDIAN TERRITORY
ARKANSAS
IOWA
ARIZONA
NEW MEXICO
LAKE HURON
LAKE MICHIGAN
TROPICAL FOREST
TROPICAL FOREST

FIG. 387.

Describe the character of any forest with which you are acquainted. What trees predominate? For what purpose are the trees mainly used? Describe any tract of land where you have seen lumbering carried on. What is the appearance of the forest after the lumbermen have left it? Are the conditions such that the land can be used for agriculture or grazing? Are the cutting down of the trees and the clearing away of the undergrowth likely to affect the flow of any stream?

Compare a forest map of the United States with a rainfall map of the same region, and note carefully the relation existing between rainfall and the location of the forest areas (Figs. 385 and 387).

What amount of rainfall appears to be necessary for forest growth? What is the meaning of the expression "timber line" as commonly used, and what conditions determine it? Do any of the mountains in the eastern part of the country rise above the timber line? What can you say as to the timber line in the Cordilleran region? Review what has already been stated in this connection (p. 293).

Distribution of the Forests and Trees of the United States. — In the arid region of the Southwest the lower limit of the forest growth is six thousand to seven thousand feet above the sea, while the upper limit is about eleven thousand feet. This lower limit decreases in elevation in every direction and in moist climates is the sea level. Upon the coast of Oregon it descends to the ocean, while in the same latitude in Idaho it has still an elevation of five thousand feet. The upper limit decreases from the tropics toward the polar regions, until, upon the borders of the Arctic region, with the steadily increasing cold, it descends to the level of the tundras and the forests disappear, except for a scrubby growth in favored localities.

Tell what main differences exist between the forests of the eastern and western United States. Are the forests of the Ohio Valley and the adjacent portions of the Appalachians chiefly made up of conifers or broad-leaved trees? Is the soil in this region such as favors the growth of pines? What is the nature of the forest belt of the South Atlantic and Gulf States? What is the characteristic soil of this region? In what portions of the country is the birch found?

The extensive hardwood forests (broad-leaved trees) of the Eastern States include the oak, elm, maple, beech, ash, hickory,

and chestnut. Among the eastern coniferous trees are the hemlock, spruce, and white, long-leaved, and short-leaved pines.

Find out what you can about the distribution of these different trees, and mention the important uses of each.

In the West, the broad-leaved trees are mostly confined to the valleys and lower mountain slopes, where the rainfall is abundant. Among these trees are the cottonwood, sycamore, alder, maple, and many species of oak.

The forests of the Rocky Mountain region contain white pine, lodge pole pine, yellow pine, spruce, and fir. The conifers of the Rocky Mountain region and of the eastern part of our country do not grow as large as those upon the Pacific coast, where the conditions appear to be particularly favorable for the production of giant trees of this class.

The forest belt of Oregon and Washington consists essentially of spruce (commonly called Oregon pine), hemlock, fir, and cedar, with some yellow pine. In California the yellow pine forests are very extensive. California also produces the sugar pine, the most valuable of all, and two species of Sequoia (the redwoods and the "Big Trees"). These forests are very dense and contain many large trees, some of which attain a height of over three hundred feet and a diameter of thirty feet. Individual specimens of the "Big Trees" are believed to be five thousand years old.

What effect upon the growth of trees has the presence of too much moisture? Describe any natural meadows with which you are familiar. What trees thrive in the moist soil of the bottom lands? Find out what kinds of trees thrive in swamps, and describe some of the southern swamps (Fig. 332).

The Uses of the Forest. — In but few places in our country has there yet been any systematic effort to use the forests in an intelligent manner, although the national government has withdrawn large tracts of forested lands, mostly in the mountains of the West, and is now developing a rational forestry system.

The methods in use for supplying ourselves with the forest products are not only exceedingly wasteful of the grown trees, but destroy the young ones as well. The surface, littered with limbs and broken trunks, is ready for the first fire, which, when once started, sweeps away every living thing; and if the conditions

Fig. 388.

Lumbering in the redwoods, Coast Ranges of California. The logs are hauled to the roadways by means of a donkey engine.

are unfavorable for the growth of young trees, the forests will permanently disappear from such areas. In places where lumbering cannot be carried on profitably without this waste, the forest should be allowed to stand until more accessible or until its products bring higher prices.

Through the Eastern States the destruction of valuable timber for the purpose of clearing the land has stopped; but in many parts of the newly settled West great waste is still allowed. Many thousands of sugar pines, which if sawed into lumber

might each be worth hundreds of dollars, have been cut down by the shake-maker,[1] and then, because they would not split well, have been allowed to rot upon the ground. Extensive groves of tan-bark oak are being cut for the bark alone, the wood being left upon the ground.

In those portions of Europe where methodical forestry has long been practiced, the trees to be cut are carefully selected with reference to their size and to their nearness to each other. The dead limbs and trunks are removed for firewood, and the under-brush, which would retard the growth of the young trees, is cleared away. While such extreme care is not practicable in our forests, there is the most urgent need for better judgment in all forest operations.

If you have access to a district which has been lumbered, describe carefully what efforts nature is making to restore the vegetation. Is the forest renewing itself or is the land growing up to useless shrubs? What care is needed to make the new growth valuable?

Describe the methods of tree cutting and the various means by which the logs are taken to points where they can be sawed into lumber. What natural conditions govern the locations of sawmills?

The Need of Forest Protection. — Before the coming of Europeans, the Indians had in places restricted by fires the natural forest growth. It is believed that the prairie region was much enlarged as a result of the annual grass fires set by the Indians. The tree-covered slopes in many parts of the West were also burned over by the Indians, so as to leave them more open for hunting purposes; but since the settlement of the country by the whites, dense young growths have sprung up over large areas (Fig. 390). The fires set by the Indians were not generally as destructive as those now occurring; for since they took place at short intervals, the ground did not have time to become covered with a litter of trunks, branches, and leaves.

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[1] A shake is a thin slab, thirty inches long and six inches wide, split from a section of a log and used for the same purposes as a shingle.

Since the settlement of the country, forest fires have destroyed more timber than has the lumberman. These fires are sometimes started through carelessness, but too often intentionally. Lightning is also the cause of many fires. Every one camping in the dry woods should be careful to put out his fire before leaving.

FIG. 389.

Brush has largely replaced the pine forest, as a result of repeated fires. Southern slope of Mt. Shasta, California.

Care should also be taken in the selection of a spot for the camp fire, so as to lessen the danger of its spreading.

In certain parts of the country, particularly in the Rocky Mountains, insects have destroyed many thousand square miles of forest. In Massachusetts great but unsuccessful efforts have been made to restrict the ravages of the gypsy moth.

Find out all that you can about the insects in your neighborhood that are harmful to trees. Describe any borings that you have seen made by beetles. What are the grubs that are found in dead portions of trees? What parasitic plant injures the trees in the South and West?

The mountain ranges of the West have been very generally used as summer pasture grounds for large numbers of cattle and sheep. The presence of so much stock has resulted in great damage to the forest. The young trees have been browsed off and the grasses have been killed, so that the water which falls in rain runs off rapidly, carrying away the best of the soil and cutting up the surface (Figs. 391, 394).

Forest Reproduction. — It often happens that when the native forest has been cut from a given tract, the same species of trees do not again occupy the surface. This is especially noticeable in the northern woods, where poplar and birch appear after the cutting down of the conifers. The reason for this is that there is a constant struggle among trees for room in the soil and for light, and those which seed the quickest and grow the fastest keep others from making a start.

In what two ways do trees reproduce themselves? Mention some of the trees whose seeds are carried by the wind. Mention some whose seeds are edible and frequently carried by animals. Another agent which is of some importance in the spread of forest trees is the network of running streams which intersects nearly all lands.

Why are trees growing close together in the dense forest so different in shape and general appearance from those growing far apart in the open? What particular advantage is it to the young trees to have the old ones removed? Where is there more undergrowth, in a dense or open forest? Give reasons for your answer.

In every region there are large tracts of hilly, rocky land, which are more valuable when given over to the reproduction of trees than when used for any other purpose. Some of these tracts contain no forests, although the conditions do not make their growth impossible. Some are covered with trees, although not with the most profitable species. Still others have been cut over, the young growth has been practically destroyed, and the ground left littered with limbs and trunks. Scientific forestry attempts to bring all such tracts back to their fullest productive

power, in addition to taking care of existing forests and superintending the cutting of trees in them.

In the attempt to replant areas such as those mentioned, various methods are employed. One method is to raise the young trees from seed in nurseries, and transplant them at the proper

Fig. 390.

Pine forest, which has sprung up since the Indians ceased burning the foothills of the Sierra Nevada Mountains.

time to the place where trees are needed. Another is to scatter or plant the seeds themselves. To cover again with trees the deforested slopes of the mountains of Southern California, great care has to be taken in the selection of hardy varieties which will stand the dry climate. In order to be successful, the planting of the seeds must be done before the winter rains.

In the West, the chief object in replanting is rather to form a protecting cover upon the mountain slopes than to afford timber for commercial purposes. In the Eastern States the object is

p. 508

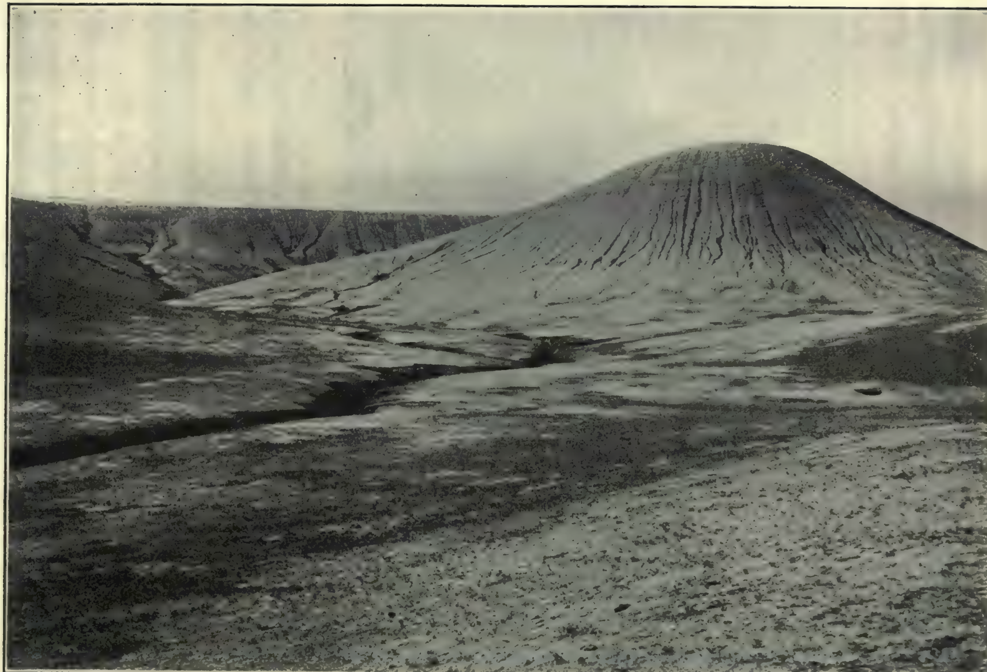

FIG. 391.

Denudation of surface, as a result of killing out the grass roots by stock. San Joaquin Valley, California.

mainly to supply wood for various purposes; yet here, also, the strength of the summer streams has been found to be affected by the cutting off of the forest cover from the mountains, and forest work has been undertaken partly to restore the natural conditions.

FIG. 392.

The important part played by the roots of trees in holding the soil. A roadside scene in the San Juan Mountains, Colorado.

Importance of the Forest Cover. — Watch the effect of a heavy rain upon a bare, sloping surface of rock. The water runs off in sheets and torrents, as from the roof of a building. A surface of bare earth sheds the water almost as rapidly, and is in turn soon marked by furrows and gullies. The sudden flood of water carries its load of silt to the valleys, filling up the channels of the streams and causing them to overflow their banks; but little of the water has gone into the ground where it fell, and the soil is soon as dry as it was before the rain.

Compare the appearance of the surface just described with one protected by a heavy grass sod, with shrubs, or with forest trees. The forest is particularly important, because of the thick layer of decaying vegetation which slowly accumulates upon the ground, and because of penetrating roots which open the rock

FIG. 393.
Denudation following the destruction of the forest cover. Warner Range, Northeastern California.

crevices and make it more easy for the water to be absorbed. The layer of decaying vegetation, or humus, takes up the water like a sponge, holding it while it slowly soaks into the earth beneath. This water goes to supply the springs, which are larger and more numerous in a forested area than in a barren one. As a result of fires, the humus layer is destroyed, and the trees, though sometimes but little burned, are blown down because of the removal of the support for their roots.

Describe from your own observations the effect upon a sloping land surface of the removal of the grasses and shrubs (Fig. 391). What is the effect of the removal of the forest cover upon the streams in spring and summer? What is the effect of draining and clearing the swamps which form the source of many of the streams in the North Central States?

FIG. 394.

Denudation in a pasture, as a result of the grass being partly killed by cattle. Coast Ranges, near San Francisco.

Find out all that you can about the animals and birds in your vicinity that make their homes in the woods or are in some way dependent upon trees. Certain insects are confined to trees, and if the latter are killed, the food supply of birds is affected.

As a result of her operations throughout a long period of time, Nature has so nearly established an equilibrium between the different forces in a forested region, that the wearing down of the surface goes on very slowly. When man comes and disturbs things, the results are often disastrous. Man cannot influence the coming and going of the rain clouds; but he can so remove

the covering which has been spread over the soil that the water will be shed in destructive floods at one time of the year, while at another time the land will be baked with dryness and heat.

Less permanent harm results from careless treatment of the forests where the rainfall is considerable and distributed through

Fig. 395.

Wasteful lumbering of the Sequoia gigantea. Sierra Nevada Mountains.

the year, because Nature quickly covers up the effects of man's work. Even in such a region, however, intelligent use of the forest cannot fail to be profitable. In the semi-arid regions the destruction of the vegetation may so overturn the balance of forces that Nature will never be able to restore the soil with its protective covering.

Review the effect of storms upon the bare mountain slopes in the arid region (p. 153).

The Forest Reserves. — To maintain the natural conditions about the heads of the streams as well as to preserve the forests

until, under careful and scientific management, the mature timber may be cut, the national government has established a system of forest reserves. These are located along the higher mountain lands and watersheds throughout the Cordilleran region, where it was judged that the necessity of preserving the slopes in their natural condition was greatest.

Several state governments have established reserves, or rather parks. There is one in Minnesota, about the head of the Mississippi River; the Adirondack Park in New York is another. Public sentiment is growing in favor of the extension of this work, and now it is proposed to form great forest reserves along the summit of the southern Appalachians and in the White Mountain region of New Hampshire.

The reserves created from the public lands are under the control of the general government, and in them a beginning has been made in scientific forestry. Forest rangers are appointed to patrol the woods in summer, put out fires, see that the stockmen do not unlawfully encroach, and last, but not least, look out for the wild animals. The animals thus protected in many of the parks and reserves are increasing in numbers and will continue to add greatly to the interest of the wild woods.

The Æsthetic Side of Forestry. — We are learning to appreciate more than ever before the beauties and wonders of the earth upon which we live, and the wrongfulness of being shut up continuously under unnatural and unhealthful conditions. To foster this love of nature and the out-of-door world, it is of the utmost importance that the rugged, mountainous parts of our country and those noted for their attractive scenic features, together with their animal and plant inhabitants, should be preserved in a natural state.

The "Big Trees" of California, which have been four thousand to five thousand years in reaching their present proportions, deserve a better fate than being blasted open with powder and sawed into boards and split into posts (Fig. 395).

CHAPTER XXIII.

IRRIGATION.

Introduction. — Water is the first essential for the existence of life, as life is constituted upon our planet. Each species of plant and animal has become adapted to the conditions under which we find it living, whether in the moist tropics, the hot deserts, or the polar regions; but none can live any length of time without more or less water.

Animals can move from place to place for food and water, and many migrate with the changing seasons; but plants are fastened in one place and have to adapt themselves to their surroundings. Hence it is that plants respond quickest to favorable or unfavorable changes in temperature and moisture.

Where there is an excess of water and a temperature not too low, there are dense, almost impenetrable swamps and forests; and where there is too little water, even though there is plenty of warmth, vegetation is scanty and dwarfed.

The plants upon which we depend for our main food supply have developed in temperate latitudes and require for their successful culture a fair supply of water. But unfortunately the rainfall is distributed over the earth so unevenly that only a small portion of its surface is adapted to the growing of these food plants. In one place the land has to be cleared of the forests at infinite trouble, and then drained of its surplus water. In another place the soil and temperature are suitable, but there is little moisture, and water has to be carried many miles to make it productive. The contrast in the appearance of the vegetation between a moist and a dry region is shown in Figs. 239 and 106.

The Rainfall of the United States. — A broad belt in which the rainfall is generally less than twenty inches annually, stretches from north to south across the western half of our country.

Review carefully the features of the rainfall map of the United States (Fig. 385).

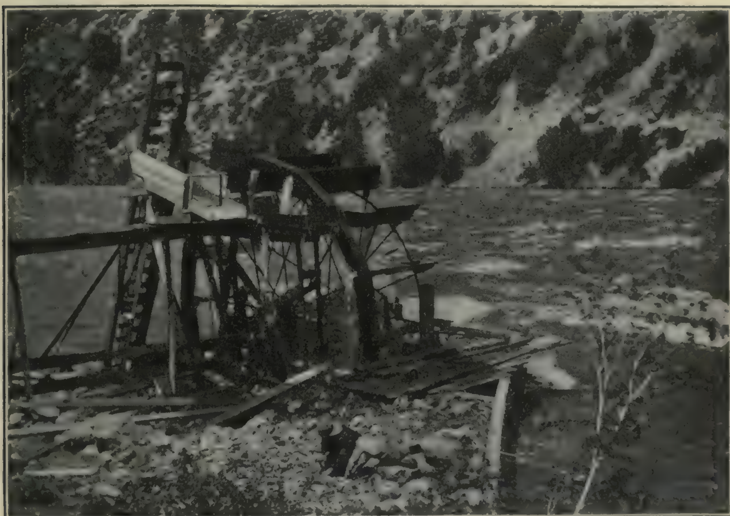

Fig. 396.

Raising water for irrigation, by means of a waterwheel. Grand River, Colorado.

Describe in detail the causes for the presence of scattered areas in which the rainfall is much more than twenty inches.

We use the term *arid* in a general way for a land where the annual rainfall is less than twenty inches. In such a region few crops can be grown successfully without artificial watering, although the distribution of the rain with reference to the seasons plays a very important part. Where the climate is cold and the precipitation occurs mainly in the fall or winter, the rainfall affords little direct benefit to vegetation. In Southern California, where

the winters are so mild that plants can grow during the period of greatest rainfall, a precipitation of ten inches is usually sufficient to produce excellent crops of grain.

How is the precipitation distributed through the seasons in the Central and Eastern States? At what time of the year occurs the precipitation

FIG. 397.

One method of constructing a reservoir dam. San Diego County, California.

in the plateau region and upon the Pacific coast? How are the rains distributed in that portion of the country bordering upon Mexico?

Explain fully the double influence which the presence of lofty mountains (where the precipitation is chiefly in the form of snow) exerts upon the summer water supply of the surrounding lowlands.

The rainfall decreases westward from the Mississippi River, the 100th meridian marking approximately the limit of successful farming without irrigation, except for favored valleys in the mountains and a strip of considerable size upon the Pacific coast.

In the extreme northwest the precipitation is very heavy, giving rise to such dense forests that much labor is required to clear the land for farming purposes.

Nearly one half the area of the United States is so deficient in rainfall that agriculture cannot be carried on without artificial watering of the land. Without agriculture, the population of this vast extent of country, much of which possesses very rich soil, must always be thin and scattered, except for a few centers whose location is determined by mines and by intersection of lines of commerce.

Describe the leading industry of that portion of the country which, although it cannot be termed desert, has a rainfall too light for farming. Is there water available to irrigate all the lands of the arid region?

Although the rainfall in the eastern portion of our country is, under normal conditions, sufficient for all purposes, yet in occasional years the summers are marked by drought. The plants then wither and crops are nearly a failure. If irrigation could be employed at such times, the returns for the labor expended would be abundant.

Describe the effects of a dry season in your locality. What are the extremes of rainfall there? What is the average rainfall?

Irrigation has one advantage over the natural rainfall, since we can control its application. The growing crops can receive the water they need, and no more, at just the time when they need it most.

Many of the ancient civilizations of the old world owed their great development to the productiveness of arid lands to which water was artificially led. In the United States there are also large areas of arid and semi-arid lands which are proving to be very productive under similar treatment and are likely to support a vast population in the future.

Origin of Irrigation in the United States. — A study of the lands surrounding the ruins of the Cliff-dwellers and the Pueblo

villages of the southwestern part of our country, shows that the ancient inhabitants of that region understood irrigation. The ruins of their canals and irrigating ditches have been found in many places.

FIG. 398.

Irrigating canal, near Riverside, California.

When the Spaniards extended their settlements northward from Mexico into New Mexico and California, they found a climate very similar to that with which they were already familiar, and so irrigation was at once undertaken. Their missions and towns were generally located near some stream where water could be obtained for irrigation. The methods which they employed were of the simplest kind, but the results which they obtained showed that water was all that was needed to make the desert-like slopes most productive.

Irrigation was practiced upon a large scale by the Mormon emigrants who settled Utah. Then it was introduced into Colo-

rado, and later into the other territories of the West. Irrigation laid the foundation for the rapid development of Southern California. Lands which once supported only jack rabbits and sagebrush are now covered with luxuriant orange orchards (Fig. 236).

Long experience was required to master fully the details of the proper application of water. It was at first considered a laborious method of farming, and the man was pitied who lived where irrigation was necessary; but it is known now that irrigated fields are more productive than any others in proportion to the amount of time and money expended upon them.

Primitive Methods. — Irrigation in its simplest form consists in taking the water from some convenient stream by means of a ditch and allowing it to flow over the land until the ground is thoroughly soaked. The ditch must be begun at a point far enough up the stream so that the water can be carried high along the sides of the valley and distributed by branch ditches to the lands needing it.

When water is found but a short distance below the surface, it may be pumped by windmill or engine in sufficient quantities for irrigation. Sometimes the water is raised from a stream by means of buckets upon a wheel turned by the passing current, and carried by a flume to the field where it is to be used (Fig. 396).

With the simple ditch or waterwheel, the floods of spring could not be controlled and the larger part of the water flowed away unused. In summer, when the most water was needed, the streams shrank to such small proportions that often there was not enough for the fields which had been tilled with the expectation that water could be applied when the crops needed it.

Control of the Flood Waters. — The first and most important condition tending to equalize the flow of streams at different seasons, and so lessen the danger of floods, is the preservation of the forest cover. If this forest cover has been destroyed, the next step is to aid its renewal by replanting.

The most important artificial means for the control of streams is the establishment of reservoirs at favorable points upon their head waters. Here the surplus waters can be held, and allowed to flow down slowly in the summer months, when water

Fig. 399.

Characteristic scene upon an irrigating ditch. New Mexico.

is most needed. A lake, so situated that its capacity can be greatly increased by a dam, may be made to serve as a reservoir, as in the case upon the head waters of the Mississippi River. A favorable site for a reservoir exists where there is a widening of a mountain canyon or valley, and below this widening a gorge-like passage through which the stream flows out. A dam built at the narrow opening can be firmly braced against solid bed rock so as to resist any water pressure. Dams are sometimes constructed by blasting down the wall of the canyon (Fig. 397), but the better ones are made of solid masonry. From the reservoir the water is either conducted in a canal down to the lands to be irrigated,

or is allowed to flow in its natural course for a distance and is then diverted into an artificial channel.

The primitive ditch dug in the rocky soil of the hillsides loses a large proportion of its water by leakage, before the fields are reached. To avoid this loss, cement-lined ditches (Fig. 398)

FIG. 400.

A flume carrying the water for irrigation across intervening canyons. Modesto Irrigating Canal, California.

or wooden flumes are constructed. From such channels the water suffers no loss except that from evaporation. In the arid region water is a precious commodity, and the more of it that can be saved, the greater will be the population which a given valley will support.

The reservoir not only stores the water for summer use, but assists greatly in doing away with the disastrous floods which often destroy so much property and carry away so much of the alluvial bottom land. Huge reservoirs have been planned for the

upper Mississippi and Missouri rivers, the purpose of which is to retain the waters of the spring floods, thus lessening the danger from overflow in the lower Mississippi Valley, and to afford more water in the river for summer navigation and for use in irrigation, particularly in the valley of the Missouri.

FIG. 401.
Irrigating an orchard by method of squares. Las Cruces, New Mexico.

The general government has undertaken a survey of the arid lands of the West for the purpose of determining upon reservoir sites at the most important points. The great storage reservoirs which it is planned to build will ultimately save a large portion of the water of this region, which now goes to waste during flood season. Thus the country will finally come to support a large population where once lived only a few half-starved Indians.

The Putting of the Water upon the Land. — Various methods of wetting the land are in use. The simplest method, and one

which can be used in nearly flat land, consists in turning the water on to the upper side of the field and allowing it to percolate gradually down until the whole is wet.

Another method of using water is "flooding by checks." In this case the land is divided up into rectangular blocks by earth

FIG. 402.

Irrigating an orange orchard by furrows. Southern California.

ridges, and the water is allowed to stand in each square successively, until the whole is thoroughly soaked (Fig. 401).

Still another method is by the use of furrows. This is shown in Fig. 402. The water is turned into shallow trenches, which are extended in such a direction that the slope shall not be sufficient for it to wash away the soil.

In some cases pipes are laid through the fields, with openings at frequent intervals. This is expensive, but lessens the loss of the water at points where it is not needed.

The water is taken from the main ditch through wooden gates, which can be opened or closed. These are known as "headgates," and not only regulate the supply to the smaller ditches, but measure the amount of water (Fig. 403).

FIG. 403.
Headgate of an irrigating ditch.

The water is usually sold by "inches." The "miner's inch" came into use during the early mining days in the West. It is an expression to designate the amount of water which flows through an opening one inch square with a pressure, or "head," of six inches. The method is not an accurate one, as the head is seldom constant and the rate of flow of the water is further affected by the shape and size of the opening.

What is the object of cultivating the orchards after irrigating them? What class of lands requires the most water? How are lands drained

which contain too much water? What is the effect of irrigation upon lands containing much "alkali"? How is this substance got rid of?

Many of the rivers of the West carry a great amount of fine silt. What effect does this have upon the ditches (Fig. 48)? How does irrigation with muddy water affect the land?

It has been found that the lands of the arid region, once thought useless, are in reality generally supplied with a good soil. All that they need is irrigation. The remarkable transformation wrought by water is the wonder of every one who has visited Southern California and Arizona.

What crops raised in your vicinity frequently fail for lack of water? Point out any basin-like valleys in your vicinity suitable for reservoir sites.

A thousand acres which before irrigation would support only a few cattle, under irrigation gives support and employment to hundreds of people. All such lands upon which water can be placed will eventually be reclaimed; and not only in the arid West, but in the moister East, will irrigation be the means of adding greatly to the value of the soil.

The most stupendous project for the transference of water from one district to another is that originating in the city of Los Angeles. It is proposed to make use of a portion of the water supplied to Owen's Valley by the streams flowing down the eastern slope of the Sierra Nevada Mountains. The water is to be conducted, in a huge cement pipe, more than two hundred miles across the Mohave Desert, and through the lofty San Gabriel range in tunnels aggregating many miles in length.

By this means the attractive region about Los Angeles, which has nearly reached the limit of its development because of the limitation of the water supply, will be enabled to support hundreds of thousands more people than at present.

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[THE REFERENCES ARE TO PAGES.]

First Principles of Physics

By Professor HENRY S. CARHART, of the University of Michigan, and H. N. CHUTE, of the Ann Arbor High School. 12mo, cloth, 422 pages. Price, $1.25.

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THIS book was prepared by the committee of teachers that was called upon to frame the syllabus in Chemistry for New York State. Its three fundamental features are:—

1. The experimental evidence precedes the chemical theory.

2. The historical order is followed as far as possible in developing the theory.

3. The practical aspects of the science are emphasized.

In selecting their material the authors have been governed wholly by what they consider its intrinsic value to the elementary student, without reference to its traditional place in a text-book.

To give the pupil some idea of the great commercial importance of chemistry a number of typical manufacturing processes have been described and illustrated. When a substance is manufactured in several ways the authors have given the process most extensively used in this country. The commercial production of copper, aluminum, iron, and carborundum has been described somewhat in detail, as these are notable examples of modern chemical processes.

An important feature is the brief summary and the test exercises given at the end of each chapter.

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Household Chemistry for Girls

By J. MAUD BLANCHARD, High School, Los Angeles, California
12mo, cloth, 108 pages. Price, 50 cents.

THE author's purpose is to outline a strong course in chemistry, especially suited to girls of high school age. Though the ultimate aim is the training of intelligent homemakers, it is a manual of chemistry, *not* of domestic science. It is therefore suitable for a purely academic high school, no less than for a polytechnic high school, where a rigorous course in household chemistry forms a necessary foundation for the work in domestic science. The choice of subjects is based in a general way on the following scheme: —

What we breathe.
What we drink and use for cleaning.
What we use for fuels and illuminants.
Chemical nature of common substances.
Foods and food values.
Adulterants and simple methods for their detection.
Textiles — care of textiles, removal of stains, etc.

The second half of the book, beginning with Experiment 28, is devoted to qualitative experiments in organic chemistry, as delicate quantitative experimentation is beyond the ability of high school pupils. Supplementary reading is of course advisable in this connection; with this in view, a full list of library text-books is given, and definite references to these accompany the experiments.

High School Physics

By Professor HENRY S. CARHART, of the University of Michigan, and H. N. CHUTE, of the Ann Arbor High School. New Edition, thoroughly revised. 12mo, cloth, 444 pages. Price, $1.25.

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